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The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
Owned and Published by The American Orthopaedic Association

January 1945

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8 THE FENWAY, BOSTON, MASSACHUSETTS, U. S. A.

Vol. XXVII, No. 1 *Published Quarterly* Old Series: Vol. XLIII, No. 1

The Journal of Bone and Joint Surgery*

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The Journal of Bone and Joint Surgery is issued quarterly — in January, April, July, and October. The subscription price, payable in advance, is $5.00 per year in the United States; $5.25 in Canada; and $5.75 in foreign countries. Single copies $1.50.

Entered as second-class matter August 1, 1921, at the Post Office, Boston, Mass., under the act of March 3, 1879, and additional entry at the Post Office, Concord, N. H., authorized May 18, 1932. Publication office, 10 Ferry St., Concord, N. H. Editorial and business offices, 8 The Fenway, Boston, Mass. Accepted at the special rate of postage provided for in the act of February 28, 1925, Paragraph 4, Section 412, Postal Laws and Regulations; authorized April 21, 1932.

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VOL. XXVII, NO. 1 JANUARY, 1945 Old Series Vol. XLIII, No. 1

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The Journal of Bone and Joint Surgery

OSTEOTOMY OF THE SPINE FOR CORRECTION OF FLEXION DEFORMITY IN RHEUMATOID ARTHRITIS *

BY M. N. SMITH-PETERSEN, M.D., CARROLL B. LARSON, M.D., AND OTTO E. AUFRANC, M.D., BOSTON, MASSACHUSETTS

"Osteotomy of the Spine" is a slightly misleading title for this paper, but it is an intriguing one, effective in stimulating interest and curiosity. The operative procedure is confined to the laminae and articular facets and does not involve the vertebral bodies.

Summary of Recent Progress in Surgery of Rheumatoid Arthritis

In 1941 the authors were granted the assignment of "Operative Procedures for the Prevention and Correction of Deformities in Rheumatoid Arthritis", at the Massachusetts General Hospital. This assignment allowed us to evaluate acromioplasty, excision of the radial head, and excision of the distal end of the ulna for the relief of pain and restoration of function to the joints of the upper extremity.[1] The technique of arthroplasty of the hip has been improved, so that more nearly perfect mechanical joints can be shaped. Progress is also being made in mold arthroplasty of the knee.

Optimum Time for Surgical Procedures in Rheumatoid Arthritis

One problem has been constantly before us, and that is the question of the optimum time for surgical treatment. Up to the present time, the generally accepted opinion has been that surgery must wait until the active stage of the disease has passed. This waiting period is a period of gradually diminishing activities, commonly terminating in recumbency in the position of minimum pain. The results of diminished or absent function are atrophy of muscle and bone (loss of elasticity of ligaments, fascia, and intermuscular septa) and development of joint deformities. Surgery performed under these conditions is technically difficult; restoration of motion is slow; and the functional end result less satisfactory than when surgery is undertaken at a relatively early stage, while the disease is still active.

Analysis of Development of Flexion Deformity and Its Surgical Correction

Recumbency in the position of minimum pain commonly results in a flexion deformity of the spine sufficiently marked to interfere with the function of the lower extremities in standing and walking, and to make the sitting position one of strain and discomfort.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 2, 1944.

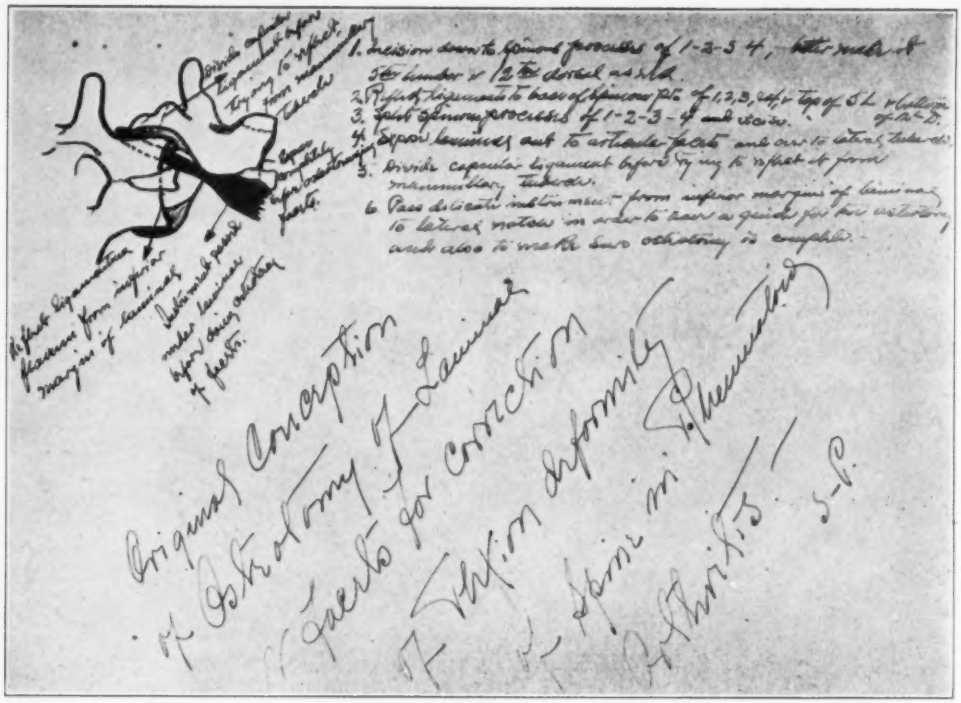

FIG. 1

Reproduction of sketch and notes made in preparation for the first osteotomy of the spine, March 1941.

Manipulation, followed by support, will improve many of these patients; it will not be of benefit after bony ankylosis of the articular facets and calcification of the longitudinal ligaments have occurred. Patients with ankylosis of both hips not infrequently present this latter extreme condition of the spine. After arthroplasties, the flexion deformity of the spine interferes to such an extent with function of the lower extremities that the problem of correction becomes most important. Analyzing the obstacles to correction, we came to the conclusion that the ankylosed facets, surrounded by overgrowth of bone, offered more resistance than any of the other spinal structures. Any surgical procedure for correction of the flexion deformity must, therefore, be aimed at the facets, articular processes, and adjacent laminae; osteotomy of these structures, with excision of sufficient bone, should allow corrective leverage to be transmitted to the intervertebral discs and longitudinal ligaments, overcoming whatever resistance these may present.

Preceding the first operation, a diagram was made and the operative steps were outlined (Fig. 1). It is rare that a surgeon is able to carry out a preconceived plan of operation, but in this case that was true; furthermore, the operation is even now essentially the same. Only six cases have been done; further experience may, and probably will, bring about improvement in the operative technique.

OPERATIVE TECHNIQUE

The lumbar region is more favorable than the thoracic, since the latter commonly presents ankylosed costovertebral joints rendering correction difficult, if not impossible. Thoracic osteotomy has been done in only one case; it resulted in subjective improvement, but there was no objective evidence of it.

Selection of the lumbar level or levels at which the osteotomy is to be performed depends on the roentgenographic findings; the less marked the ossification, the better the chance of correction.

FIG. 2

1: Exposure and reflection of supraspinous and interspinous ligaments. Beginning reflection of periosteum with its muscular and ligamentous attachments from the spinous processes and laminae.
2: Drawing of specimen showing bony ankylosis of articular facets.
3: Two spinous processes have been osteotomized into lamellae, to be used as bone grafts; the third spinous process is being osteotomized in a similar manner.

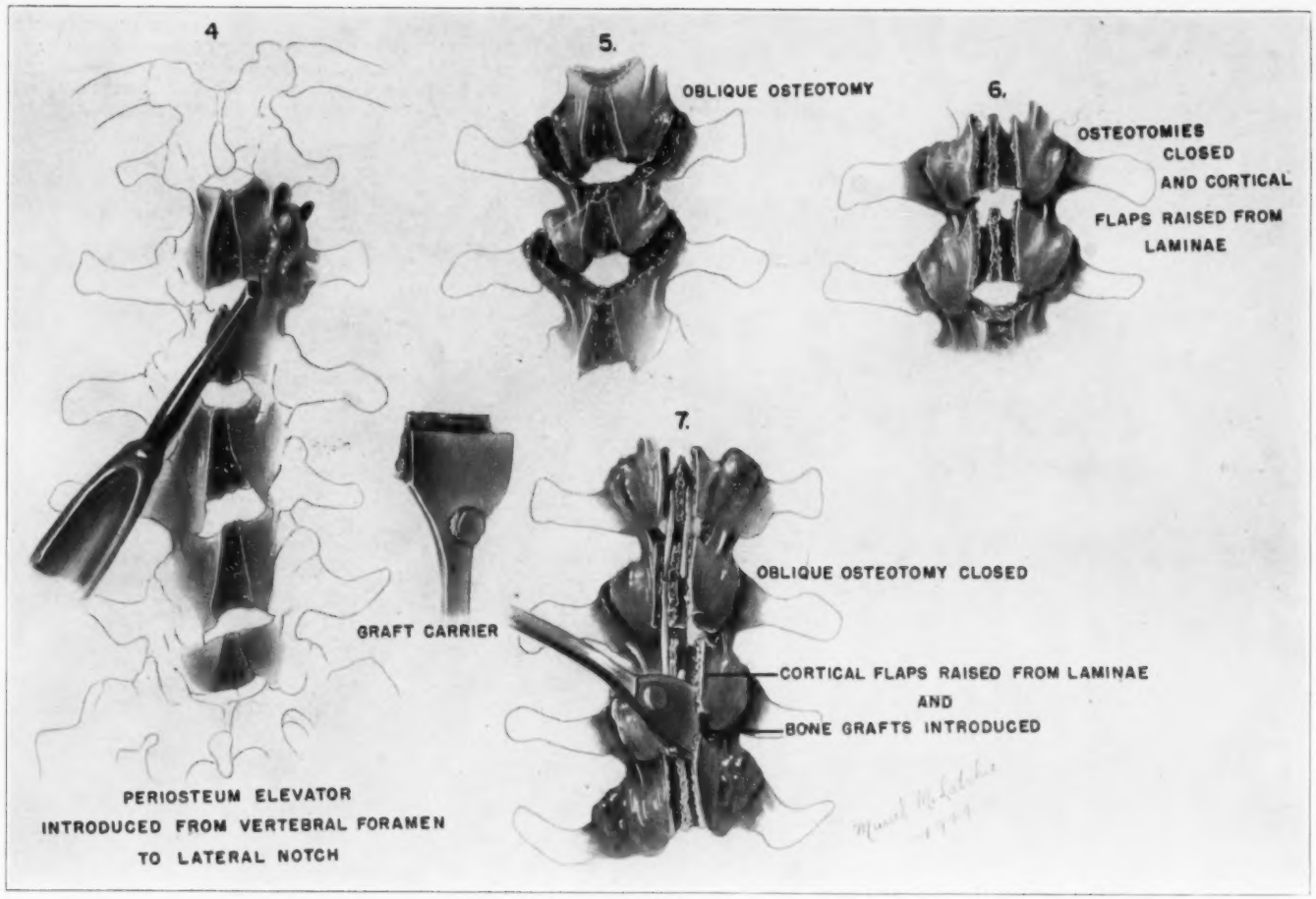

FIG. 3

4: Periosteum elevator has been introduced anterior to lamina and articular process; its point is seen at the intervertebral or lateral notch.

5: The oblique osteotomy has been completed at two levels. (The diagram is correct, but is misleading in so far as the space created is concerned,—there should be a space of one-quarter to three-eighths of an inch between the osteotomy surfaces.)

6: The head and foot of the operating table have been raised and the osteotomy spaces have been closed. Cortical lamellae have been raised from the laminae.

7: Bone grafts, obtained from the spinous processes, have been introduced into the laminae. The bone-graft carrier is shown in position.

Operative Steps

Through an incision in the mid-line, at least three lumbar spinous processes are exposed. Even if the osteotomy is performed at one level only, the spinous process above and below that level must be completely exposed and excised in order to allow adequate retraction (Fig. 2, *1*).

The second step consists of the incision and reflection of supraspinous and interspinous ligaments, followed by the subperiosteal reflection of muscle attachments from the spinous processes and laminae.

The spinous processes are then osteotomized into lamellae with a thin osteotome, and are excised at their bases (Fig. 2, *3*). This allows further reflection of the periosteum from the superior and inferior articular processes, exposing the intervertebral notch as well as the articular facets. The reflection of the periosteum must be accompanied by division of the muscular attachments to the ligamentum flavum.

By means of a periosteum elevator, the ligamentum flavum is detached from the inferior margin of the lamina and inferior articular process. The elevator is then advanced anterior to the lamina and inferior articular process until it appears in the lateral intervertebral notch just above the articular facet (Fig. 3, *4*); it serves as a guide to the direction of the osteotomy through the superior articular process of the vertebra below and the inferior articular process of the vertebra above. The osteotomy is done in an oblique plane, at an angle of approximately 45 degrees with the frontal plane (Fig. 3, *5*). The osteotomes should be narrow and thin-bladed; both straight and curved osteotomes are required. Gouges of the same type are sometimes useful. A rongeur with narrow jaws is indispensable. The osteotomy is performed at one, two, or three levels, depending upon the extent of new-bone formation in relation to the facets and intervertebral discs.

Upon completion of the osteotomy or osteotomies, leverage in the direction of extension is applied by raising the head and foot of the operating table very slowly. The gradual narrowing and final obliteration of the oblique spaces between the laminae and between the remnants of the articular processes marks the "high-spot" of the operation. The obliquity of the osteotomy ensures locking and prevents any serious displacement (Fig. 3, *6*).

By means of delicate osteotomes, bone flaps are raised from the laminae adjacent to the osteotomy, and the bone lamellae obtained from the spinous processes are inserted by means of a bone-graft carrier. These grafts bridge the gap between the laminae, and consequently hasten bony fusion in the corrected position (Fig. 3, *6* and *7*).

In closing the wound, close apposition of the split interspinous and supraspinous ligaments is important. If the approach is developed with proper regard for structures and structural planes, the closure and nature's repair of the wound are facilitated.

Postoperative Care

A plaster shell is applied and kept on for four to six weeks, followed by a plaster jacket or back brace, to be worn continuously for a year or longer. Since complete correction is never obtained, it is important to guard against recurring deformity by having the patient wear the brace part of the day for two or three years postoperatively. It is hardly necessary to emphasize the importance of exercises for control of posture, as well as for maintaining chest expansion.

ASPECTS OF OPERATIVE TECHNIQUE DEMANDING EMPHASIS

1. The operative procedure must not be belittled,—there are many points in the technique that we have found difficult.

2. In developing the approach, it is more important to follow structural planes and preserve hemostasis than to save a few minutes in operating time. The osteotomy is in itself difficult, and demands a dry field.

raised from the laminae.
7: Bone grafts, obtained from the spinous processes, have been introduced into the laminae. The bone-graft carrier is shown in position.

3. The spinous processes must be excised before an attempt is made to expose the articular processes and intervertebral notch.

4. The interspinous ligament and the ligamentum flavum have been found ossified, sometimes partially, sometimes completely. In excising the ossified ligamentum flavum, one should keep in mind that the dura is apt to be adherent to it and is, therefore, easily punctured. A leak of spinal fluid is in itself of relatively little consequence, but it does add another problem to the operative technique.

5. In introducing the elevator for the purpose of reflecting the periosteum from the anterior surface of the lamina, care must be exercised in order to avoid injury to the dura and spinal nerves. The inflammatory process which has resulted in the articular destruction is accompanied by periarticular adhesions and inelastic structures, not easily reflected.

6. The bone instruments should be of a delicate type,—they are intended to cut, not crush.

7. The possibility of overcorrection must be kept in mind. If the thoracic spine presents marked flexion, there is apt to be compensatory extension deformity of the cervical spine with motion in the occipitocervical joints only. In the presence of such deformities, overcorrection in the lumbar region makes it difficult for the patient to see his plate on the dining room table and to read without holding the book on a level with his head.

FIG. 4-A
Before treatment.

FIG. 4-B
After treatment.

Case 1, N.B.; aged twenty-three years; duration of condition, eight years.

Operations:

March 1941: Osteotomy of lumbar spine at level of first and second, and second and third vertebrae.
December 1941: Osteotomy of thoracic spine at level of ninth, tenth, and eleventh vertebrae.
February 1943: Arthroplasty of left hip.
March 1943: Arthroplasty of right hip.

Present condition:

The patient is using crutches and wears a back brace part of the time. He tires easily, but says he has no pain, and can sit quite comfortably.

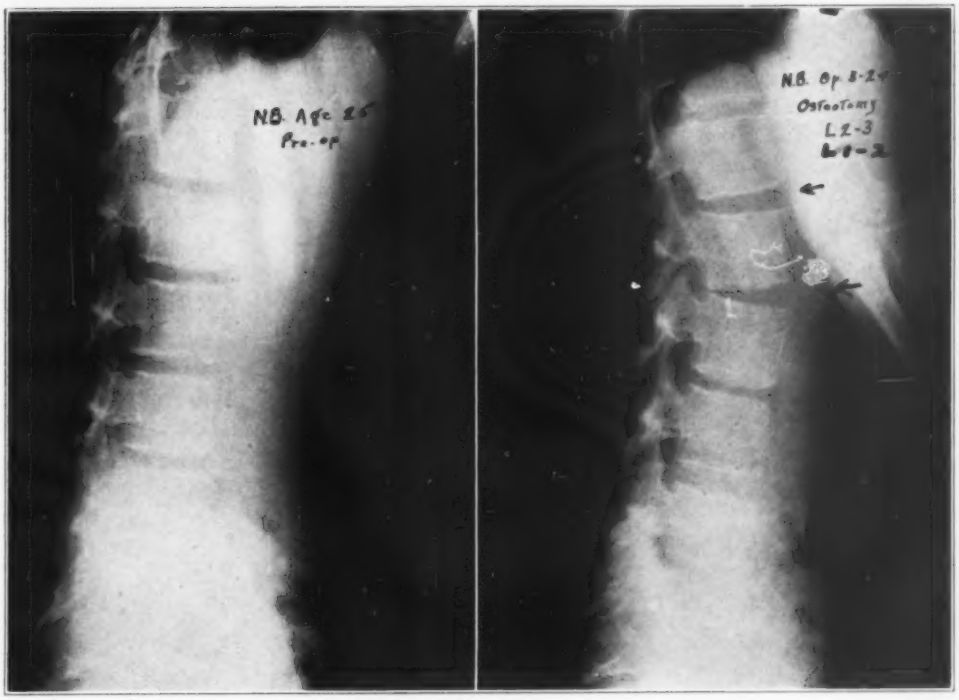

FIG. 4-C
Before treatment.

FIG. 4-D
After osteotomy.

The postoperative roentgenogram shows definite widening of intervertebral spaces between the first and second lumbar and the second and third lumbar.

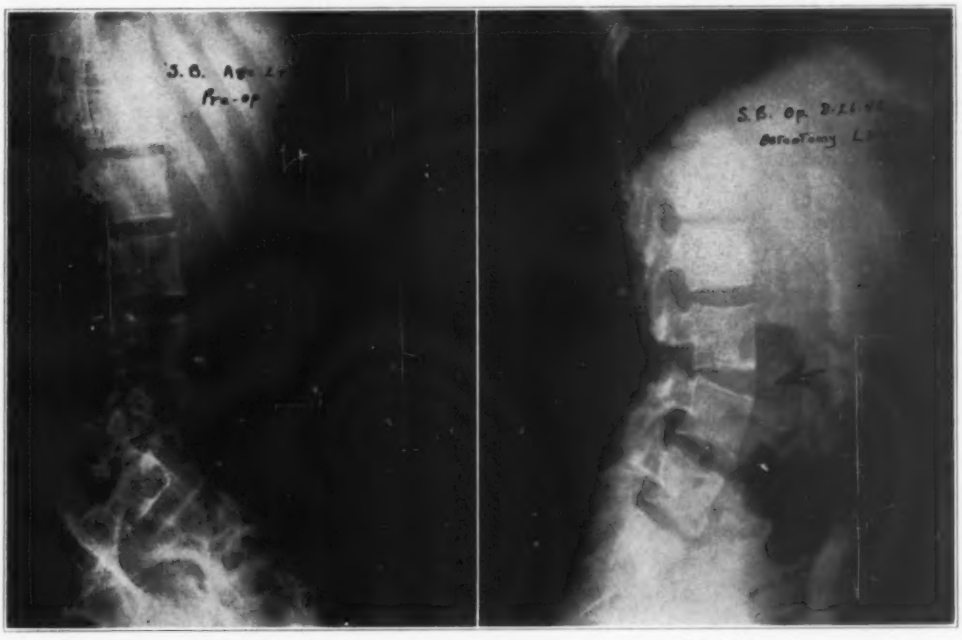

FIG. 5-A
Preoperative roentgenogram.

FIG. 5-B
After osteotomy.

Case 2, S.B.; aged twenty-four; duration of condition, six years.

Joints in order of involvement were right hip, spine, and left hip. Patient left college to have right hip fused for "tuberculosis". Postoperative immobilization in double plaster spica for one year resulted in ankylosis of spine in flexion, with both hips in flexion and abduction.

(*See page 8.*)

FIG. 5-A and FIG. 5-B (*continued*)

Operations:

June 1942: Arthroplasty of left hip. Bony ankylosis.
July 1942: Arthroplasty of right hip. Bony ankylosis.
August 1942: Osteotomy of lumbar spine and fusion with grafts from spinous processes.

Fig. 5-A: Preoperative roentgenogram. Fig. 5-B: After osteotomy of lumbar spine at level of third and fourth vertebrae.

Present condition:

The patient returned to college in October 1942. He is still using crutches at times, two canes most of the time. He is able to sit comfortably, and eight months ago resumed playing the piano.

FIG. 6-A

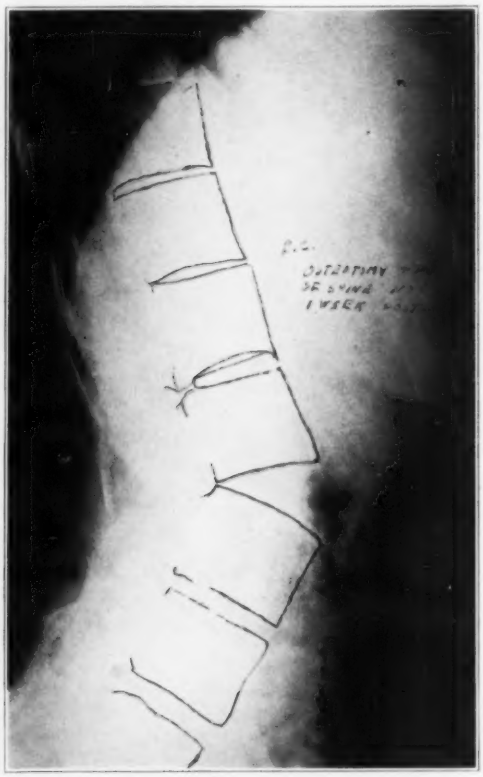

FIG. 6-B

Case 3, B.C.; aged thirty years; duration of disease, eleven years.

Joints in order of involvement were spine, hips, and jaws. Patient had been "frozen" in sitting position for seven years.

Operations:

February 1940: Arthroplasty of right hip.
April 1940: Arthroplasty of left hip.
September 1941: Gauze sponge removed from right iliac fossa. Operative wound healed *per primam*, but a small sinus developed one year later.
October 1941: Osteotomy of lumbar spine at level of second and third vertebrae.
November 1941: Fusion of osteotomized area.

Fig. 6-A: Roentgenogram before osteotomy. Fig. 6-B: Roentgenogram one week after operation showed marked correction at level of osteotomy, and consequently fusion was indicated.

Present condition:

The patient is using crutches or canes, occasionally only one cane. He is working eight hours a day, six or seven days a week, and says he has no pain. He goes fishing and hunting.

FIG. 7-A and FIG. 7-B (*See page 9.*)

Case 4, R.F.; aged twenty-four years; duration of condition, two and one-half years.

Joints involved: Hips and spine.

Operations:

July 1942: Arthroplasty of left hip.
August 1942: Arthroplasty of right hip.
March 1943: Osteotomy of lumbar spine, and fusion.

Fig. 7-A: Preoperative roentgenogram. Fig. 7-B: After osteotomy of lumbar spine at level of the second and third and third and fourth intervertebral spaces, with fusion at the time of osteotomy.

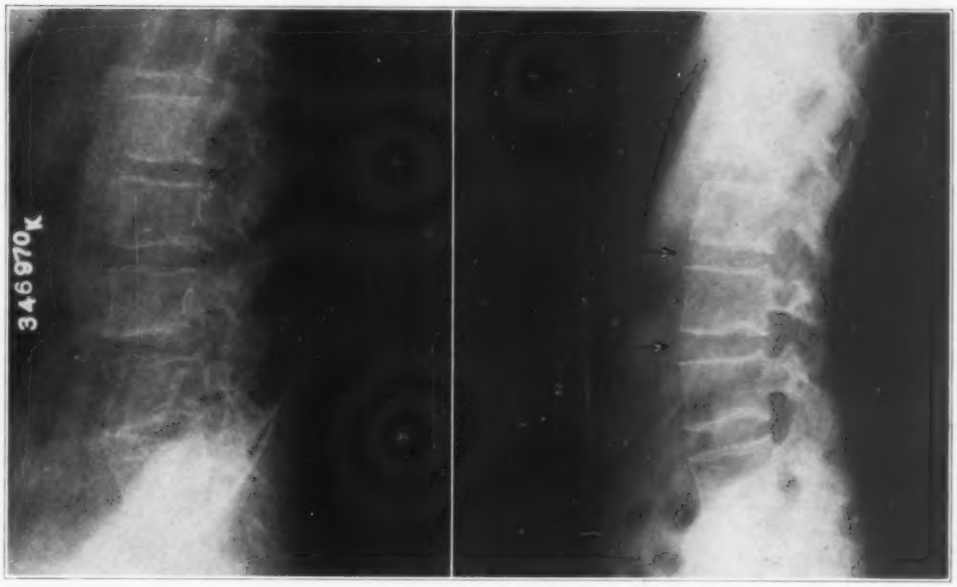

FIG. 7-A FIG. 7-B

Postoperative treatment: Plaster jacket was used for three months, followed by brace and exercises.
Present condition:

Patient uses crutches most of the time, occasionally two canes. He is studying drafting, and says he has no pain.

FIG. 8-A FIG. 8-B

Case 5, J.W.; aged thirty-five years; duration of condition, ten years.

Joints involved: Spine and hips.
Operations:

June 1938: Arthroplasty of left hip for bony ankylosis.
May 1941: Arthroplasty of right hip for fibrous ankylosis.
September 1943: Osteotomy of lumbar spine with fusion at the level of the third and fourth vertebrae.

Fig. 8-A: Before osteotomy. Fig. 8-B: After osteotomy of the lumbar spine with fusion.
Present condition:

Patient is able to run and ride a bicycle. He uses crutches at times, otherwise one or two canes.

FIG. 9-A FIG. 9-B

Case 6, H.C.; aged thirty-six years; duration of condition, four years.

Joints involved: Hips and spine.

Operations:

September 1942: Arthroplasty of right hip for fibrous ankylosis.

October 1942: Arthroplasty of left hip for fibrous ankylosis.

November 1943: Osteotomy of lumbar spine with fusion at level of the fourth and fifth vertebrae.

Fig. 9-A: Preoperative roentgenogram. Fig. 9-B: Roentgenogram after osteotomy of the lumbar spine with fusion.

Present condition:

Patient is able to navigate about the house without crutches or canes, but does have occasional discomfort.

CONCLUSIONS

1. Surgical intervention in rheumatoid arthritis should be undertaken early, before secondary deformities develop.

2. Flexion deformity of the spine frequently results from delayed surgical treatment of the hips.

3. Such flexion deformity may be sufficiently severe to demand surgical correction.

4. Osteotomy of the spine, performed in a small series of six cases, has yielded satisfactory results.

1. SMITH-PETERSEN, M. N.; AUFRANC, OTTO E.; AND LARSON, CARROLL B.: Useful Surgical Procedures for Rheumatoid Arthritis Involving Joints of the Upper Extremity. Arch. Surg., XLVI, 764, 1943.

DISCUSSION

DR. GEORGE E. BENNETT, BALTIMORE, MARYLAND: Many years ago I had the honor of opening the discussion of a paper by Dr. Smith-Petersen—his first paper on the introduction of the Smith-Petersen nail. That was a subject I could talk on with perfect freedom, because I had had a great deal of experience with the operative reduction of fractures of the neck of the femur. Later, I had the honor and privilege of discussing his paper on the use of the vitallium cup for arthroplasty of the hip. That was also a subject about which I could talk from experience. Today I am confronted with opening the discussion on an operation on which I have had absolutely no experience. I can only say that this is an operation designed by a man who is one of the master-surgeons of his generation. I can see that it has its place. I know none of the older men are going to do this operation, unless they do a little work on the cadaver. As Dr. Smith-Petersen said, this operation should be reserved for the cases in which all conservative treatment has failed. I think again Dr.

Smith-Petersen has presented an operation developed by a genuine master-surgeon. Unless you are a master-surgeon, do not try it!

DR. H. R. MCCARROLL, ST. LOUIS, MISSOURI: This is an operative procedure I have never done, I have never seen, and, until about one month ago, I had never heard of. Any discussion by me must, therefore, be entirely theoretical.

First, there can be no objection to any procedure, regardless of how technically difficult it may be, which offers the unfortunate patient with a flexion deformity of the spine from Marie-Strümpell disease some hope of being able to look the world in the face once more. There are three points, however, which should, I think, be taken into consideration:

(1) The question as to whether or not these deformities should be fairly complete before surgery is done. If they are still in the formative stage, the deformity may recur. This in turn prompts the question of whether or not enough motion remains in the intervertebral spaces to allow correction of the deformity, if bone already bridges the interspaces along the anterior longitudinal ligament;

(2) The prospect of a surgical correction for the deformity should not prevent us from making every attempt to prevent the flexion deformity from developing. During the early stages of the disease, adequate conservative measures will accomplish this in some patients;

(3) This operation is not one to be undertaken by an amateur. Many of us have attempted exploration of a spine for a possible disc lesion after a previous spinal fusion. The technical difficulties encountered in the two operations are essentially the same. Such an exploration is one of the most difficult of all orthopaedic operations and should never be considered lightly.

DR. M. N. SMITH-PETERSEN, BOSTON, MASSACHUSETTS (closing): I have been very fortunate in having Dr. Bennett discuss all my first presentations of what I have considered new procedures. He discussed one procedure which he did not mention,—namely, that of acetabuloplasty. In his discussion he warned me that this procedure was not going to turn out as well as I expected; he was right. Evaluating the results of this operation, five years after I operated on the first case, I found that only 50 per cent. of the cases were satisfactory to the patient and to the surgeon. Since the advent of mold arthroplasty, we rarely do acetabuloplasties.

I want to thank Dr. Bennett for his encouraging discussion.

Dr. McCarroll asked three questions: The first was about the deformity being fixed before surgery is done. The operation is not undertaken until conservative measures have failed; it is performed in the lumbar region at levels showing a minimum of bony bridging. Such bony bridging may be expected to yield after osteotomies of the articular facets.

The second point that Dr. McCarroll raised is that of prevention of flexion deformity. This point can not be overemphasized, but, in spite of conscientious efforts in this direction, flexion deformities will occur every so often.

Finally, Dr. McCarroll points out the technical difficulties of the operation. I have emphasized this point in my paper, and Dr. Bennett has also referred to it. The operation is a difficult one and should never be undertaken lightly.

I want to thank Dr. McCarroll for his thoughtful discussion.

OSTEOCHONDRITIS DISSECANS OF THE SUPRATROCHLEAR SEPTUM

BY H. S. MORTON, SURGEON COMMANDER,
AND W. E. CRYSLER, SURGEON LIEUTENANT COMMANDER
Royal Canadian Naval Volunteer Reserve

From the Royal Canadian Naval Hospital, Esquimalt, British Columbia, Canada

Loose bodies in the elbow joint have not been previously classified and distinguished from accessory bones in this region. The nomenclature of abnormalities at the lower end of the humerus and the upper end of the radius and ulna is confusing, and consequently a consideration of the various terms and their definition seems advisable. These conditions may be divided into four classes: congenital, developmental, traumatic, and degenerative.

1. In the congenital group there are two terms: "sesamum cubiti", which was coined by Pfitzner, when he described the sesamoid bones, and "patella cubiti", a name introduced by Keinböck, which may be defined as the counterpart of the kneecap in the elbow.

2. Under developmental abnormalities may be placed the accessory bones in association with the olecranon process. The variations of the upper end of this process, as seen in the lateral views of the elbow, are numerous; the process may have near it a single rounded nodule, or there may be one or two small isolated bones just proximal to the upper end. Again, the upper end may be separate, in one large piece. These variations are almost normal findings, and they are thought to be accessory bones, formed from a secondary center of ossification, which have failed to unite with the main mass of bone. They are usually bilateral and may be associated with other comparable developmental anomalies. The first case reported in English, was published in 1942 by O'Donoghue and Sell. The lower end of the humerus may have discrete medial or lateral epicondyles.

3. The traumatic group is the largest. Separation of epiphyses includes the olecranon epiphysis, the upper epiphysis of the radius, as well as the lower end of the humerus, especially the medial epicondyle, which may be displaced by trauma, and thus may become a loose body in the elbow joint. The capitellum (capitulum humeri) and the lateral epicondyle may be similarly displaced into the joint. Fractures around the elbow joint may produce loose bodies. Osteochondritis may occur in the capitellum, the head of the radius, and also in the supratrochlear septum.

Pathological fractures in this region may lead to loose-body formation.

4. This group includes those cases in which degeneration is the dominant feature, but the degenerative changes do not lead to the formation of loose bodies except in association with trauma. In arthritis, usually hypertrophic, fracture of an osteophyte may produce a loose body. Avascular necrosis originates with trauma, but progresses because of interruption of the blood supply. Traumatic ossification results from a lifting up of the periosteum by trauma, followed by a hematoma and the degenerative change of calcification. With this is associated myositis ossificans. Degenerative ossification, such as osteochondromatosis, occurs in the villi and may lead to multiple loose bodies.

OSTEOCHONDRITIS DISSECANS

It is now proposed to present osteochondritis dissecans arising from a situation at the lower end of the humerus, a specific lesion not previously described.

The supratrochlear septum, when present, is a thin lamina of bone, separating the coronoid from the olecranon fossa and varying in thickness from 0.5 millimeters to one centimeter. The relationship of the synovial membrane to the septum is important. Anteriorly, the coronoid fossa is entirely within the elbow joint; while posteriorly, the synovial reflection passes across the upper portion of the floor of the olecranon fossa, so that only the lower half or two thirds lies within the elbow joint.

According to Hirsh, the septum is always present until the age of seven years, after which the bony plate occasionally becomes absorbed to form the supratrochlear foramen. This foramen is of great interest to anthropologists, who claim it as one of the points in establishing the close relationship between man and the lower animals. Hirsh quotes examinations by Martin which revealed the presence of the supratrochlear foramen in 58 per cent. of Arkansas Indians studied, and in 21.7 per cent. of African Negroes; but showed the proportion to be only 4.2 per cent. in white Americans. The same authority states that the supratrochlear foramen is consistently more common in the female by 38 to 10 per cent., and on the left side by 25 to 5 per cent., depending upon the race examined.

When the elbow is fully flexed, the coronoid process of the ulna fits into the coronoid fossa of the humerus, while in full extension the olecranon process impinges on the floor of the olecranon fossa. In the extremes of movement of this joint, there is apt to be repeated trauma to the septum, which may lead to osteochondritis dissecans.

Osteochondritis dissecans, first described by Koenig in 1889, is a non-infectious aseptic necrosis of a segment of subchondral bone, affecting principally the long bones of the extremities, and resulting in an osteocartilaginous sequestrum, which may lie as a free body in the joint. The necrosis appears to be due to interference with the vascular supply; trauma seems to be the chief etiological agent. The sequestrated fragment is covered with intact cartilage, and the subchondral necrotic bone is separated from the normal bone by a bloodless fibrous-tissue bed. The microscopic picture is one of necrosis with low-grade, productive, aseptic inflammation. Foreign-body giant cells are present. Roentgenographic examination is recognized as the principal method of diagnosis.

These observations are based on six cases, of which five have been confirmed by pathological examination. As far as we are aware, these are the first published cases of osteochondritis dissecans in the supratrochlear septum.

CASE REPORTS

CASE 1. R. J. W., thirty-two years of age, was a carpenter before joining the Navy. Fifteen years ago he had first noticed a pain like a sharp stab in the right elbow, with no radiation. He had had a number of attacks which lasted from one day to two weeks; intervals between attacks varied from two weeks to six months. The most recent attack had been in June 1943, and had lasted one week. He had been playing baseball a few days before, and attributed the limitation of movement and pain to this excessive use. He also stated that, if he used his right arm in hammering too much, trouble almost invariably followed. He did not seek medical treatment, as the pain gradually subsided. While duck-hunting in 1932, he had received a gunshot wound of the left elbow. Many of the pellets were palpable, and more were seen on the roentgenogram.

Clinical examination revealed the maximum point of tenderness to be deep-seated and immediately above the tip of the olecranon process. The range of movement was 54 to 100 degrees on the right and 50 to 175 degrees on the left, with full pronation and supination.

Roentgenographic examination of both elbows showed a separate button of bone, measuring 1.5 centimeters in width and one centimeter in height, situated in the supratrochlear septum of the right elbow (Fig. 2-A). The ossicle was surrounded by a narrow but complete translucent zone, and the density of the bone appeared unaltered. There was no evidence of fragmentation. The lateral projection showed the ossicle, 0.8 centimeters in diameter, and undisplaced (Fig. 2-B). The adjacent bone structures looked normal.

The supratrochlear septum of the left elbow was perforate, producing the so-called supratrochlear foramen. An accessory ossicle was demonstrated just below the medial epicondyle. Numerous circular metallic densities, measuring three millimeters in diameter, and having the appearance of lead shot, were present throughout the soft tissue of the left elbow region.

The diagnosis was probable osteochondritis dissecans of the supratrochlear septum of the right humerus.

On July 12, he was admitted to the Hospital, at which time there was no localized pain in the right elbow. Two days later an operation was performed under local anaesthesia, the posterior approach being used through the tendon of the triceps. When the floor of the olecranon fossa was reached, the loose body could be palpated with the examining finger, but could not be removed until a small incision was made into the capsule of the joint. A loose body, two centimeters in diameter, was found lying on the floor of the olecranon fossa, partly inside the capsule of the joint, and partly embedded in the humerus. This body was lifted out with a pair of forceps, and the wound was closed in layers without drainage. The patient was discharged from the Hospital on July 16, 1943. Two weeks later, when the stitches were removed, he had complete movement of the elbow joint of 55 to 185 degrees. He has continued on duty ever since without symptoms.

The specimen removed consisted of a white calcified body, with a rather honeycombed surface partially covered with cartilage, and measuring 20 by 15 by 7 millimeters (Fig. 1). Microscopically, the calcified body was composed of a central area surrounded by necrotic bone, which in turn was surrounded by an irregular layer of cartilage, some of this being necrotic. There were also foci of calcification present. The surface was covered with hyaline cartilage and fibrous tissue, except in one area, where there was a niche which was surrounded by necrotic cartilage and bone (Fig. 2-C).

The pathological diagnosis was osteochondritis dissecans.

Roentgenographic examination of the right elbow, after removal of the described button of bone, revealed what appeared to be a supratrochlear foramen, quite similar to that on the opposite side.

CASE 2. E. P. M., twenty-four years of age, had been in the Navy for seven years as a gunner, and was serving in two Canadian destroyers at the time of their respective sinkings. He did not remember incurring any injury to his elbow, although after the loss of one of the ships he had been admitted to a hospital in Plymouth with concussion, and abrasions of his leg.

The first attack of pain in the right elbow, however, was in September 1939, and it began without aggravating circumstances. This lasted one week and gradually subsided. The estimated limitation of movement at that time was about 25 degrees. The second attack occurred in April 1943, and began after more than ordinary use. This lasted one week, during which time a roentgenogram was taken. After being under medical observation until September 6, 1943, he was admitted to the Hospital.

Roentgenographic examination of both elbows revealed an irregularly oval and circumscribed button of bone, located in the supratrochlear septum of the right humerus (Fig. 3-A). The ossicle measured 1.5 centimeters in width, one centimeter in height, and one centimeter in thickness. The lateral projection (Fig. 3-B) revealed that the ossicle had been displaced anteriorly, so that it lay in the coronoid fossa.

The left elbow revealed a somewhat thinned supratrochlear septum. The adjacent bone structures and joint surfaces looked normal, and there was no evidence of any intra-articular foreign body.

The tentative diagnosis was osteochondritis dissecans of the right humerus.

At operation, a lateral incision was made over the supracondylar ridge, and was deepened through the muscle layers to the anterior aspect of the supratrochlear septum, close to the bone. A loose body, completely detached from the floor of the supratrochlear septum, was found at the upper limit of the right elbow joint. The normal synovial membrane was incised, and the loose body was lifted out. No other fragments were visible or palpable. The synovial membrane was closed and the wound was sutured.

The pathological picture showed the specimen (Fig. 1) to consist of a hard, whitish body which measured 16 by 11 by 8 millimeters. One surface was smooth and the other surface was honeycombed. Microscopically, the specimen was partially covered by fibrous tissue and perichondrium, and was composed of hyaline cartilage, a portion of which contained foci of calcification. Other parts were necrotic (Fig. 3-D).

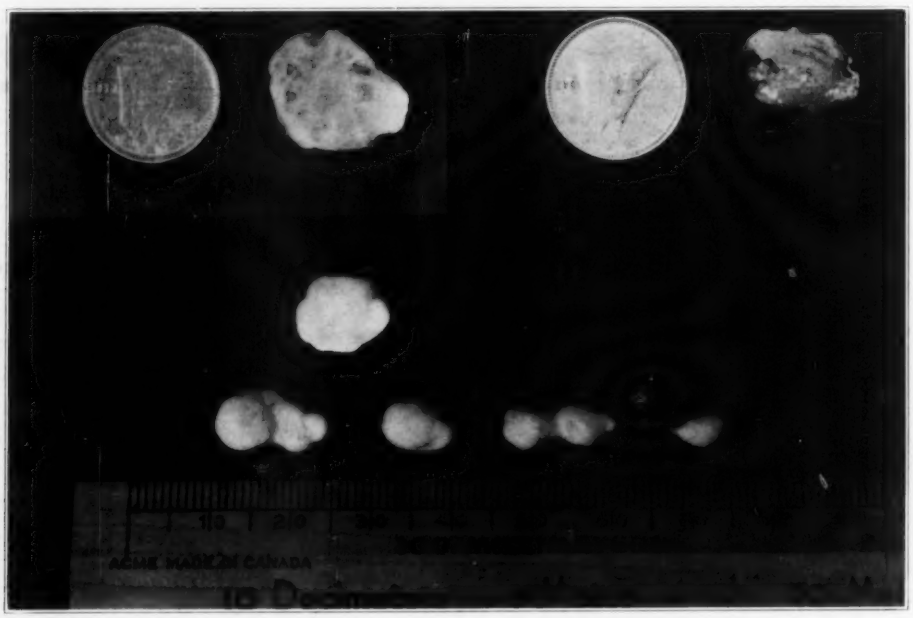

FIG. 1

Actual size of ossicles removed from four cases. The specimens are: top left, from Case 1; top right, from Case 2; center, from Case 6; and bottom, from Case 5.

The diagnosis was cartilaginous loose body (osteochondritis dissecans).

Three weeks after the operation, the wound had healed by first intention, and the patient had full flexion and 170 degrees of extension. When seen two weeks later, he was found to have regained full movement of the elbow joint, and was returned to full duty. He has remained well ever since.

Roentgenographic examination of the right elbow after removal of the ossicle revealed a thin supratrochlear septum, centrally situated, which was bordered by bone of increased density (Fig. 3-C).

CASE 3. L. L., twenty-one years of age, in May 1943, noticed pain in the left elbow which lasted two days, with limitation of movement. He had had a similar attack in February, when his left elbow had

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 1. A separate ossicle arising from the supratrochlear septum of the right humerus.
Fig. 2-B: The ossicle is undisplaced.

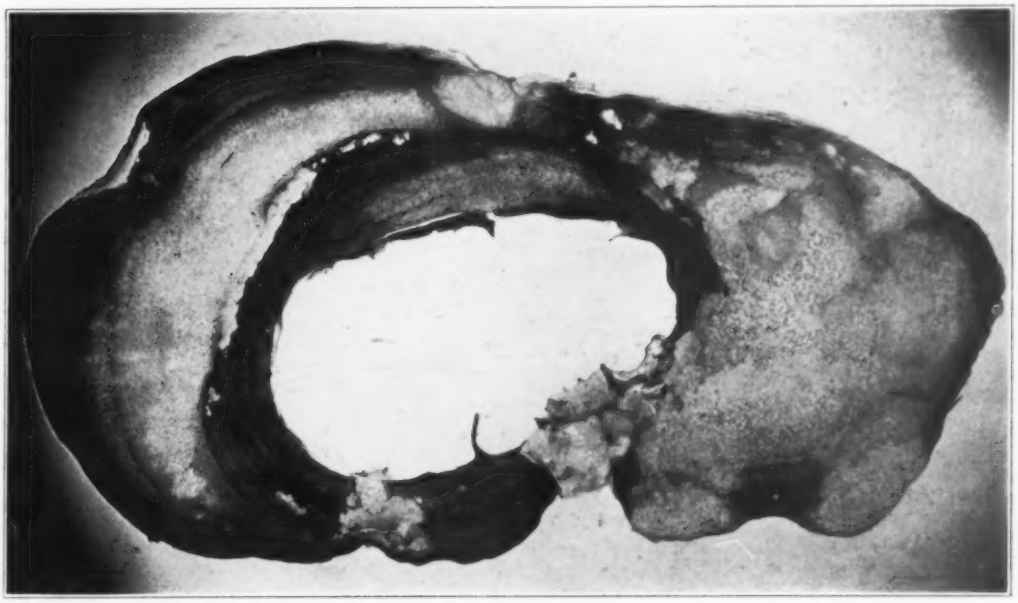

FIG. 2-C

Section of ossicle, magnified twelve times.

FIG. 3-A

FIG. 3-B

FIG. 3-C

Fig. 3-A: Case 2. A circumscribed ossicle situated in the supratrochlear septum of the right humerus.
Fig. 3-B: The lateral view shows the ossicle in the coronoid fossa.
Fig. 3-C: The right elbow after removal of ossicle.

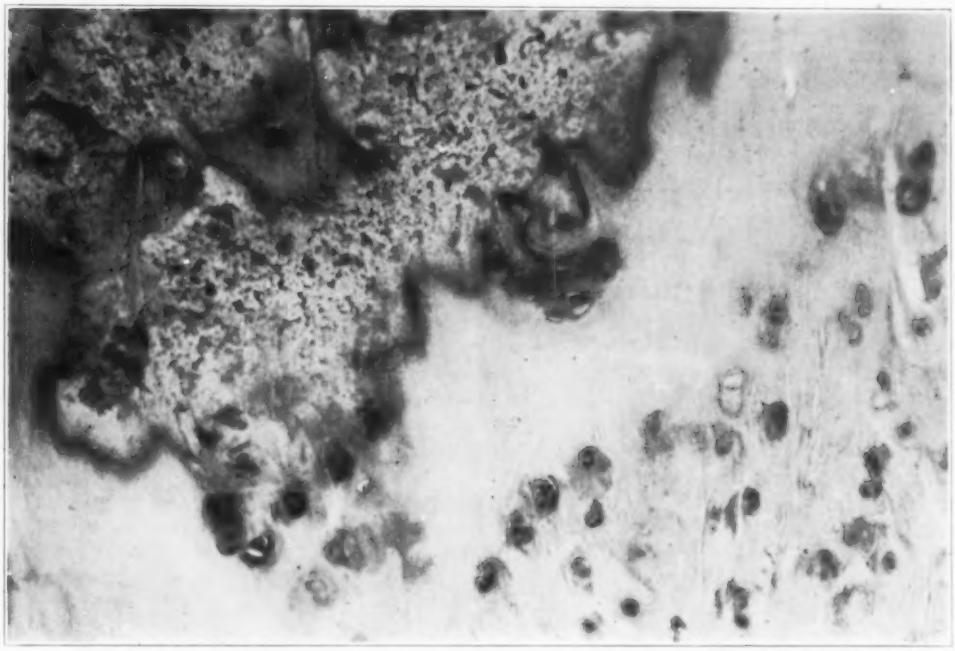

FIG. 3-D

Microscopic section of specimen under high power.

locked, and this had lasted four days. There was no history of injury. The pain did not radiate; it was centralized just above the olecranon process.

Examination showed that he had a range of movement from 70 to 160 degrees in the left arm, while the range was from 50 to 180 degrees in the right arm. There was 75 per cent. of pronation and supination of the left forearm. His work in the Navy as a stoker was comparatively strenuous, and before joining the Navy he had been a laborer. The movement of the elbow is illustrated by photographs (Figs. 4-A and 4-B), taken during the second attack, and one week later, respectively.

Roentgenographic examination of the left elbow in the frontal projection revealed a circular button of bone with normal density, bordered by a translucent zone, approximately one centimeter in depth (Fig. 4-C). There was no displacement (Fig. 4-D). The button showed no evidence of destruction, bone production, or fragmentation. There was no indication of an intra-articular foreign body, and the adjacent bone structures and joint surfaces appeared normal.

The right elbow revealed an extremely thin supratrochlear septum (Fig. 4-E). In other respects the bone structures and adjacent joint surface looked normal.

The diagnosis was osteochondritis dissecans of the supratrochlear septum of the left humerus.

Excision of the loose body was recommended, but has not yet been done, since the patient is now serving at sea.

CASE 4. T. K., thirty years of age, had bumped his elbow, four years previously, on a large aluminum cathode used in zinc plating. The elbow was sore for one week, and roentgenograms were taken (Figs. 5-A and 5-B). In September 1942, when throwing onto his shoulder a dunnage bag, weighing about 100 pounds, his left elbow locked. By manipulation of the affected arm, it was unlocked.

On February 17, 1943, an operation was performed to remove a loose body in the left elbow joint.

The diagnosis was osteochondritis of the capitellum.

After the operation, the arm was very painful for about a week. Full movement was never recovered, but there was no recurrence of pain or locking.

In December 1943, while reviewing the roentgenograms of the elbow joint to determine the presence of osteochondritis dissecans of the supratrochlear septum previously missed, the patient's roentgenograms were found to be positive.

Films were made of the left elbow in various directions. There was no sign of recent fracture. There was, however, evidence of a loose body of bony density, measuring approximately one centimeter in its widest diameter, in the region of the lateral condyle of the humerus. The articular surface of the condyle was irregular; the joint spacing was normal.

The appearance was that of a healed osteochondritis with formation of a loose body (Figs. 5-C and 5-D).

On December 24, an operation was performed and a loose ossicle was removed from the left supratrochlear fossa. Under general anaesthesia, a three-inch curved incision was made in the antecubital fossa, lateral to the biceps tendon, and was deepened to the elbow joint. The nerve was retracted laterally and the joint capsule was opened. The loose body lay immediately below the incision. It was grasped with forceps and was easily removed. The joint capsule was closed, and the wound was sutured in layers.

The specimen included a number of small fragments of bone and cartilage which together measured 20 by 15 by 6 millimeters. The specimen was composed partially of pieces of hyaline cartilage which was fibrillated in some areas (Fig. 5-E). Other portions of normal-appearing hyaline cartilage were attached to simple lamellar bone, the cells of which stained well.

The pathological report showed that the specimen included (1) fragments of an osteocartilaginous body and (2) normal bone from the supratrochlear septum.

Postoperative roentgenographic examination was made of the left elbow and compared with the previous series. The loose body situated in the coronoid fossa had been removed, except for a small fragment of calcification remaining in this region. Also a minute fragment, connected to the lateral condyle of the humerus, not previously demonstrated, was identified. The portion of this condyle, previously described as the focus of the osteochondritis, had been removed.

Six weeks later the patient had no pain, but some tenderness was present at the lower end of the wound. The range of movement was from 184 to 50 degrees on the right, and from 167 to 56 degrees on the left, with full pronation and supination. Slight weakness was seen in extension of the thumb and fingers, with moderate loss of ulnar deviation. This was attributed to temporary compression of the radial nerve by retraction during the operation. He was returned to full duty but continued to receive physiotherapy and remained under medical observation. On March 24, 1944, he had full pronation and supination with flexion from 176 to 55 degrees, while the power of the left hand was normal.

Case 5. W. M., twenty years of age, had first noticed pain in the left elbow in April 1943, while working in a railway freight department. He found that he could not lift a 150-pound carton because of pain in the right elbow, which he could not localize. Full extension or flexion of the elbow was impossible. He consulted the Medical Officer who advised bathing the affected joint in hot water.

For the first six months in the Navy, the patient was driving an ambulance and had no difficulty because he did not lift weights. One month before admission, he was helping to move a heavy lathe, when he felt a sharp pain in the elbow. When he stopped pushing, the pain stopped. On November 29, while carrying a carton of beer, he was forced to drop it, because of the pain in the left elbow. This discomfort lasted a week.

FIG. 4-A

Case 3. The range of movement of the left elbow during an attack.

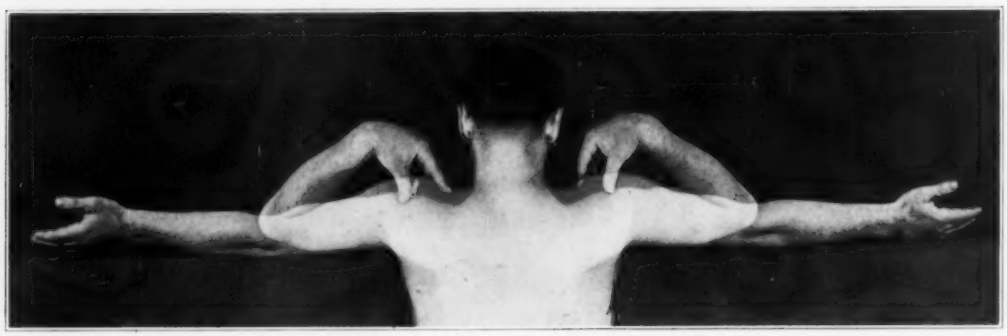

FIG. 4-B

Showing the range of movement one week later.

FIG. 4-C

FIG. 4-D

FIG. 4-E

Fig. 4-C: The ossicle in the supratrochlear septum of the left humerus.
Fig. 4-D: Showing the ossicle undisplaced.
Fig. 4-E: The right elbow, with very thin septum.

Clinical examination, January 5, 1944, revealed slight tenderness in the antecubital fossa in the upper inner quadrant. Movement of the left elbow was from 157 to 50 degrees, and of the right elbow from 175 to 45 degrees. The diagnosis was osteochondritis dissecans of the supratrochlear septum.

Roentgenographic examination was made of both elbows. A separate ossicle, lying in the coronoid fossa of the left elbow, measured approximately seven millimeters in diameter in the frontal projection, and three millimeters in diameter in the lateral view. This seemed to be rising from the supratrochlear septum of the humerus. The right elbow joint and adjacent bone structures seemed normal. The supratrochlear septum appeared to be of average thickness.

An incision was made in the antecubital fossa to the lateral side of the biceps tendon, was deepened

FIG. 5 A

FIG. 5-B

Fig. 5-A: Case 4. Anteroposterior view of the left elbow, showing ossicle in supratrochlear septum.
Fig. 5-B: Lateral projection, showing ossicle in coronoid fossa.

FIG. 5-C

FIG. 5-D

Four years later, anteroposterior and lateral views.

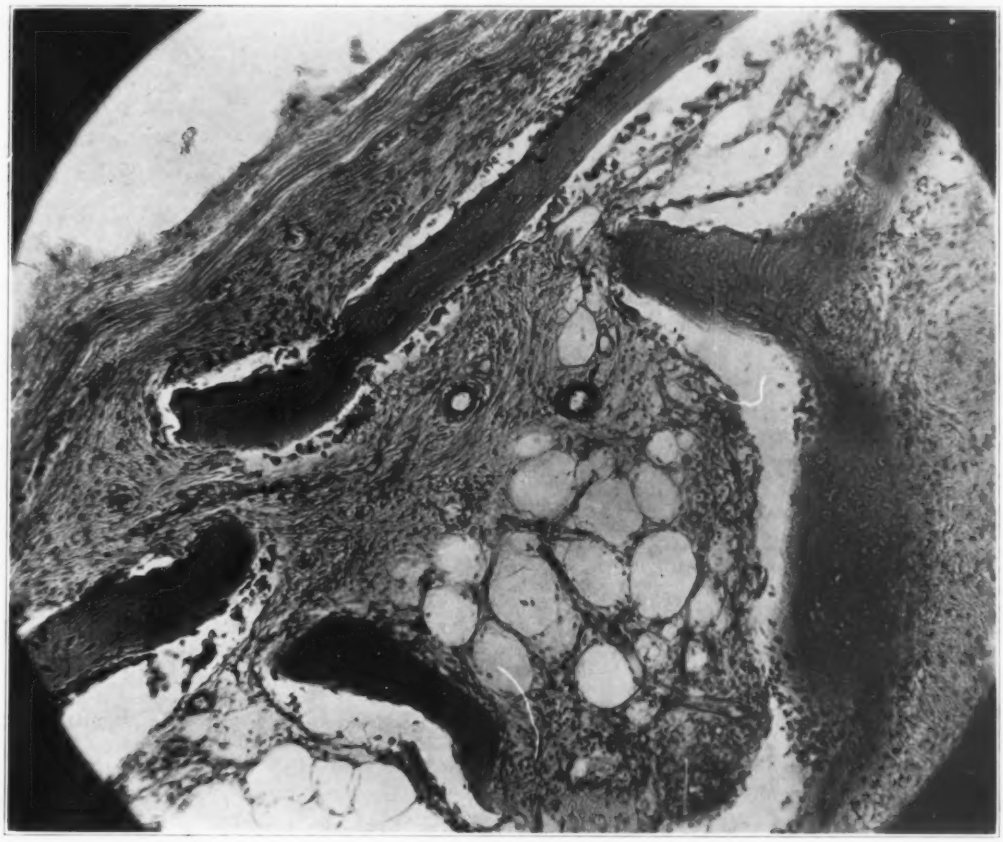

FIG. 5-E
Photomicrograph of specimen.

through the brachialis muscle, and the joint was exposed. The elbow was flexed, and the synovial membrane, found to be thickened anteriorly, was incised. A piece was removed from the coronoid fossa, and a specimen of the floor of the fossa was taken for section. The wound was closed in layers without drainage.

The specimen consisted of four hard, whitish bodies with smooth surfaces, the largest of which measured 16 by 7 by 4 millimeters, and the smallest approximately 6 by 5 by 4 millimeters. There was also a small piece of soft, grayish tissue (Fig. 1). Microscopically, the whitish bodies were composed chiefly of hyaline cartilage, throughout which were small or larger irregular areas of bone, some necrotic.

The membrane was composed of loose, fibrous, and adipose tissue, the surface of which was thrown up into short, blunt villi covered with mesothelium and infiltrated to a mild degree by lymphocytes.

The pathological report showed (1) loose osteochondromatous bodies (probably secondary osteochondritis dissecans) and (2) normal synovial membrane.

A postoperative roentgenographic examination of the left elbow region demonstrated that the separate ossicle in the coronoid fossa of the left elbow had been removed. The coronoid fossa appeared to be clear, with some possible roughening at its base.

Two weeks after the operation, the range of movement was 175 to 45 degrees on the right, and 165 to 45 degrees on the left. The patient complained of a tight feeling on lifting the edge of a desk, but had no other symptoms. He was returned to duty and has been seen at regular intervals with no complaints.

CASE 6. A. S. C., nineteen years of age, first noticed pain in the right elbow joint in February 1943, the day following a softball game. The pain lasted five or six days, and was localized in front of the elbow in the upper, outer portion. He also had difficulty in extending and bending the elbow, which persisted one and a half weeks. Treatment consisted of wearing a sling one week. No roentgenogram was taken.

On December 24, 1943, he noticed pain in the right elbow, which greatly increased during the next three days. Any lifting made the pain worse. On December 31, while helping to load a ship and while lifting a 100-pound container, he felt a sudden pain in the right elbow which prevented him from continuing his job. He could not bend his elbow or straighten it out fully.

Clinical examination revealed tenderness in the antecubital fossa, in the upper inner quadrant. The range of movement of the left elbow joint was from 60 to 162 degrees.

FIG. 6-A

FIG. 6-B

Fig. 6-A: Case 6. Anteroposterior view of the right elbow, showing ossicle in supratrochlear septum and so-called bone island.

Fig. 6-B: Lateral view, showing ossicle in coronoid fossa.

A preoperative roentgenographic examination was made of the right elbow. A separate ossicle was demonstrated in the coronoid fossa of the lower end of the humerus, which had arisen from the supratrochlear septum, thereby creating a supratrochlear foramen. The ossicle appeared to be lying completely free from the adjacent bone surfaces; it measured seven millimeters in diameter. The density of the bone bordering the supratrochlear foramen was somewhat increased. An island of bone was present in the medial epicondyle. No further change was apparent. The findings were those of osteochondritis dissecans with complete separation (Figs. 6-A and 6-B).

Removal of the ossicle was done January 12, 1944. An incision was made lateral to the biceps tendon and was deepened until the joint was exposed. The elbow was slightly flexed and the synovial membrane was incised. The synovial membrane was normal, and one large ossicle was found in the coronoid fossa. This was lifted out and the floor of the fossa was curetted. It was found to be perforated. The wound was closed in layers without drainage.

The specimen consisted of a hard, whitish nodule which measured 12 by 10 by 8 millimeters (Fig. 1). There was also a small piece of membrane. Microscopically, the specimen was composed largely of hyaline cartilage, containing foci of necrosis and of calcification and ossification. The surface was partially covered by cellular fibrous tissue. The piece of membrane was composed of fibrovascular tissue, and one surface was thrown up into blunt projections, covered by a layer of flattened mesothelial cells.

The pathological report showed (1) osteochondromatous joint body (probably secondary to osteochondritis), and (2) normal synovial membrane.

Roentgenographic examination was made of the right elbow region and demonstrated that the separate ossicle, which was previously shown in the coronoid fossa of the lower end of the humerus, had been removed.

Two weeks later, the range of movement of the right elbow was 50 to 174 degrees. There was no pain.

On March 20, 1944, no evidence of tenderness was found and the scar was well healed. There was full range of movement of from 48 to 178 degrees. After two months of full duty, the patient said the arm did not bother him when lifting, bending, or in any ordinary use.

CLINICAL ASPECTS

The clinical characteristics of these cases include recurrent attacks of pain in the elbow joint, with localized tenderness above the tip of the olecranon process or in the upper part of the antecubital space, lateral to the biceps tendon, associated with limitation of movement both in flexion and in extension. Locking occurs only when the ossicle

becomes a loose body, and migrates into the joint. The attacks last from a day to a fortnight, and gradually subside. They are usually brought on by excessive use. At operation, the bony button can usually be lifted easily out of its bed. The choice of approach depends upon the position of the ossicle as revealed by the lateral roentgenogram, and may be either anterior or posterior.

The six cases all show the same lesion, which has been best observed in the frontal projection of the elbow. Here is seen, depending upon the degree of separation, a sharply demarcated, circular or oval button of bone, which, if undisplaced, possesses normal density; it is located in the intra-articular portion of the supratrochlear septum. The lateral projection demonstrates the thickness of the ossicle, and confirms its position. When separation takes place, partial or complete extrusion of the ossicle into the humero-ulnar joint may occur, either forward into the coronoid fossa, or backward into the olecranon fossa, thus producing a loose body in the joint.

LITERATURE

In the literature, six cases have been reported in which an ossicle was found in or near the supratrochlear septum. None of these, however, was described as osteochondritis dissecans. We do not wish to suggest a diagnosis for these cases, but would like to summarize them and discuss the differential diagnosis.

In 1927, Hirsh showed roentgenograms of the right elbow in a man fifty years of age with a small round ossicle of bone in the supratrochlear foramen, which he labelled "sesamum cubiti" after Pfitzner. In the same year, Grauer reported a bean-sized swelling in the right elbow of a male, twenty-six years of age. This he removed from the floor of the olecranon fossa, to which it was attached by firm-textured bands. One year later, Winckler, reporting in the same journal, presented two roentgenograms of the right elbow of a boy, fifteen years of age. At operation, a cartilaginous, bony ball, one centimeter in diameter, was removed from the floor of the olecranon fossa. Quoting Grauer and Hirsh, Winckler called it "sesamum cubiti".

In 1933, Atsatt published a report of a loose body of an unusual form and location found in the elbow joint. He described a spherical bony mass, half the size of a marble, in the supratrochlear region, and stated that removal was simple. The following year Kleinberg, writing on osteochondromatosis of the elbow, described the case of a male, forty years of age, and presented a roentgenogram of his right elbow. This showed, among several loose bodies of the joint, a circumscribed shadow in the olecranon fossa. The patient refused operation. This is an incidental finding in a case of osteochondromatosis, and is not ascribed to this condition. Burman, in 1941, presented a case of an "unusual body in the right elbow joint" in a male bartender, calling it "sesamum cubiti". This dime-shaped piece of bone, felt beneath the triceps, interfered with extension of the elbow. A roentgenogram showed a definite round shadow in the supratrochlear septum.

These are the six reported cases, of which four are called "sesamum cubiti", one, a loose body, and one, an associated finding in a case of osteochondromatosis.

Köhler, in commenting on Grauer's case, considers that, as the elbow on the other side was normal, this was either an accessory bone or some condition other than "sesamum cubiti". It is to be noted that Pfitzner's work on sesamoid bones and, incidentally, on "sesamum cubiti", was done prior to the discovery of the roentgen ray. Grauer in 1927 used the term, and since then, Hirsch, Winckler, and Burman have described similar cases and have likewise clung to the name without the expedient of microscopic investigation.

DISCUSSION

In all of our cases which came to operation, the histological findings were those of osteochondritis dissecans. There is nothing to indicate that the condition is anything but

a sequestrating lesion of the supratrochlear septum, without evidence of bone infection. The manifestations do not differ from those seen in osteochondritis dissecans in other sites. An accessory ossicle of the olecranon process may be confusing in the frontal view, as it is projected through the superimposed supratrochlear septum or foramen. The lateral view should show it clearly.

It is interesting to note the similarity in the roentgenographic appearance of the supratrochlear foramen and the picture after the removal of the ossicle of osteochondritis dissecans. The presence of a thin septum or foramen on the opposite side was seen in our cases; this precludes the development of osteochondritis dissecans, because only with repeated minor traumata to the thick septum can the lesion occur.

In a consideration of the relationship of osteochondritis dissecans in this site to the supratrochlear foramen, two theories present themselves. As the anthropological examinations have been carried out almost exclusively on the dried specimen, may it not be possible that a proportion of the foramina have been produced by osteochondritis dissecans and the separated ossicle has been lost? On the other hand, the resolution of the septum, which normally takes place after the age of seven years, may not proceed according to plan, and thus, in conjunction with trauma, may produce the separate ossicle.

Thus we conclude that a more precise terminology should be applied to loose bodies in the elbow joint, and that such loose bodies should be removed and subjected to microscopic examination. A larger series of cases with detailed information should help to elucidate the cause of osteochondritis dissecans.

NOTE: The authors are indebted to the late Dr. Gordon A. McCurdy, pathologist at the Royal Jubilee Hospital, Victoria, British Columbia, for his kindness in preparing the pathological reports and slides.

They wish to thank Dr. M. E. Krause, for permission to use the roentgenograms taken in 1938 (Case 4).

Their thanks are also due the Photographic Department of the Royal Victoria Hospital, Montreal, and the Photographic Section of the Royal Canadian Navy for cooperation in preparing the illustrations.

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RETARDATION OF BONE GROWTH BY A WIRE LOOP *

BY S. L. HAAS, M.D., SAN FRANCISCO, CALIFORNIA

From the Surgical Laboratory, Stanford Medical School, and Shriners' Hospital for Crippled Children, San Francisco

There are three methods available for length equalization of unequal lower extremities. The long bones of the shorter limb may be lengthened; portions of the bones of the longer limb may be resected; or the bone growth of the longer extremity may be arrested by destroying the epiphyseal cartilaginous plate. Each method has its advantages and disadvantages, varying with the individual underlying anatomical and mechanical factors that may be present. There is no satisfactory method of stimulating bone growth. It has been suggested from time to time that roentgenotherapy, sympathectomy, periosteal stripping, and direct irritation of the epiphyseal cartilaginous plate would produce length increase in a bone, but the results of these methods are variable, and, to date, of no practical value. If a successful method of growth stimulation were devised, it would supplant

FIG. 1-A

Dog 3-W.B. Showing wires as originally inserted.

FIG. 1-B

Showing unfastened wire loop and partial restriction of length growth fifty-five days later.

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 2, 1944.

to a considerable extent our present procedures for correcting inequality in the length of the lower limbs.

It was during a series of experiments, in which an endeavor was made to stimulate bone growth, that the observation was made which led to the method to be described in this paper. It was thought that, if a constant abnormal stimulation could be applied to the epiphyseal plate, an increase in the activity of the cartilage cells would take place, and growth would increase. Venable and Stuck have shown that, if two metals of different potentials are inserted into the body tissues, an electric current is generated between them, causing heat and electrolysis. It was assumed that, if two different kinds of metal were inserted into or around the epiphyseal plate, they would act as a constant stimulator to the cells, and that growth increase would take place. Suffice it to say that, in a series of experiments, where various combinations of metals were placed around the epiphyseal plate, no additional growth in length took place in the bones.

FIG. 2-A

Dog 4-W. Showing wire as originally placed.

FIG. 2-B

Showing the opened wire loop. The restraining force of the wire has caused 2.5 centimeters loss of growth.

In one of the series of stimulation experiments, a free wire loop was placed around the epiphyseal plate in the frontal plane. As growth took place and the epiphysis grew distally, the wire loop opened up. In comparing the two extremities at the conclusion of the experiment, it was noticed that there was a loss of growth in the limb with the wire loop. This loss was interpreted as being due to the restraining tension of the loop, which

FIG. 3-A

Dog 9-1. The wire has been passed through the plate diagonally. There is a greater loss of growth on the lateral side of the plate than on the other.

FIG. 3-B

Gross specimen, showing the discrepancy in length.

had hindered normal length growth. Following this observation (that longitudinal growth of bone could be mechanically hindered), a series of experiments was performed, in which a wire loop, passed around the epiphyseal plate, bound the epiphysis to the diaphysis. This was done to confirm the previous findings and to determine whether or not the method had practical value.

Before describing these experiments, a brief review of the mechanism of length growth is in order. We know that there is no interstitial growth in normal growing bone. A small amount of growth is due to the expansion of the articular end of the epiphysis, as shown by Siegling in his observations on phosphorus feeding. Length growth is dependent upon an intact epiphyseal cartilaginous plate. The longitudinal columns of cartilage are responsible for length growth, and are the important portion of the epiphyseal plate. These columns of cartilage are a part of the epiphysis. The provisional buds of cartilage and osteoid tissue expand by cell growth and multiplication, pushing the epiphyseal cap away from the metaphysis, and thus increase the length of the bone. The force exerted by this growth in the lower extremities in the erect position must be strong, to raise the weight of the body, as well as to overcome muscle tension. The force in recumbency would not have to be so great, and it would be expected that length growth would be greatest during the time the body was flat, providing circulatory and metabolic processes were uniform.

A few representative experiments will be described, in which operations to retard the longitudinal growth of bone were performed upon dogs. Results will also be reported in two growing children in whom the same method of inhibition was utilized.

Measurements of length in the following experiments have been taken directly from

the roentgenograms. The amount of growth from either epiphyseal plate was determined by measurement from a fixed point on the wire on the diaphyseal side. Errors are minimal, since care was taken to employ the same distance from the target to the bone, and from the bone to the plate, in the roentgenograms of each dog.

Experiment 3-W.B

Method. After exposure of the distal portion of the radius of a growing dog, a wire was passed transversely through the epiphysis. It was then turned proximally along the periosteum, across the epiphyseal cartilaginous plate, and back through the diaphysis transversely. The two ends were then hooked together under tension. Thus the epiphysis and diaphysis were bound together by the wire loop which passed completely around the plate. An additional piece of wire was placed through the epiphysis within the loop (Figs. 1-A and 5).

Result. Fifty-five days later, the wire loop was found unfastened and opened (Fig. 1-B). The length growth of the normal side was 3.5 centimeters, and that of the side operated upon 2.5 centimeters; 1.3 centimeters of growth had taken place from the upper end of the bone, and 1.2 centimeters from the lower end. Growth was not entirely stopped, but was impeded about 1 centimeter. The wire loop impeded all growth, until it became unfastened, and then impeded growth only to the extent of the force necessary to open the wire.

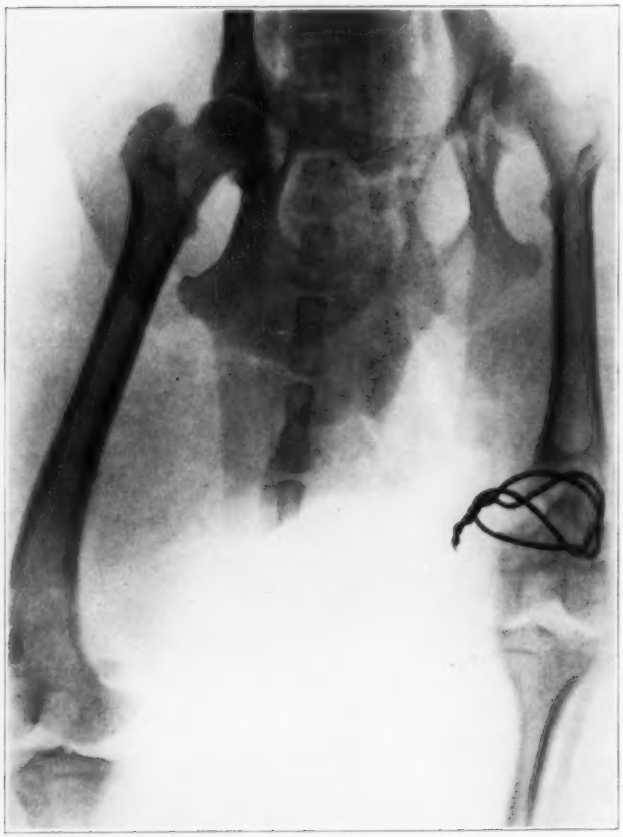

FIG. 4

Dog 9-B. A double loop of wire has been placed about the lower epiphyseal cartilaginous plate of the femur, causing 2.0 centimeters loss of growth.

Experiment 4-W

Method. A wire was inserted through the distal radial epiphysis of a growing dog, as in the preceding experiment, over the epiphyseal plate, and back through the diaphysis. The ends were overlapped and left free (Figs. 2-A and 5).

Result. At the end of 117 days, there had been 2.2 centimeters loss of growth in the limb which had been operated upon. Figure 2-B shows how the wire loop was distorted by the growth of the bone. There was a total growth of 5.5 centimeters in the normal limb, and 3.3 centimeters in the limb which had been operated upon; 1.9 centimeters of this growth was from the upper plate, and 1.4 from the lower plate. A considerable force must have been necessary to open the loop of wire. (The normal ratio of growth of the radius is 20 per cent. from the upper plate and 80 per cent. from the lower plate.)

Experiment 9-1

Method. A German silver wire, just under 0.12 of a centimeter (three sixty-fourths of an inch) in diameter, was passed transversely through the distal epiphysis of the radius of a growing dog; then it was passed diagonally through the epiphyseal cartilaginous plate to emerge on the diaphyseal side opposite. It was then passed transversely through the diaphysis and diagonally back through the plate to emerge on the side of the epiphysis approximately where it started. The ends were fastened together by twisting. Thus the diaphysis was bound to the epiphysis through the plate by a wire figure-of-eight (Fig. 5).

Result. Two hundred and eighty-three days later, there was 4 centimeters of growth on the normal side. The radius which was operated upon showed 2.2 centimeters loss of growth on the lateral side and 1.7 centimeters loss on the medial (ulnar) side. The discrepancy between the two sides was due to the fact that the wire broke on the lateral side, and did not pass vertically across the epiphysis. This allowed more growth on the lateral side, thus making an oblique joint articulation (Figs. 3-A and 3-B).

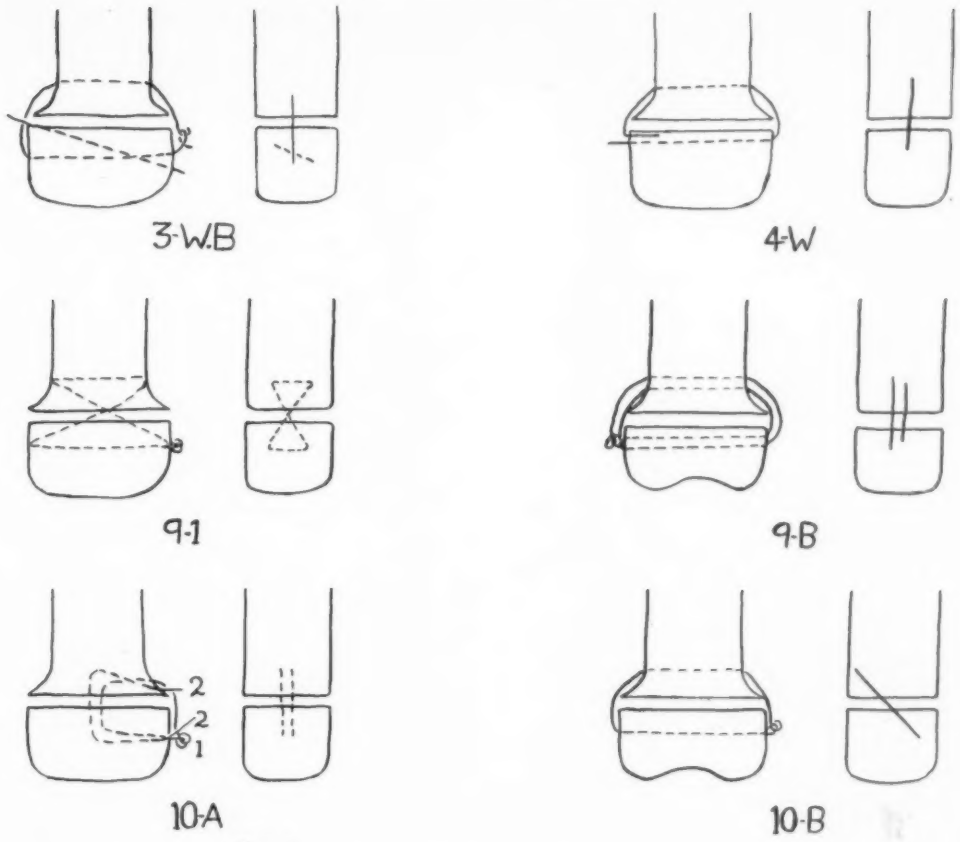

FIG. 5

Diagrammatic representation of the procedures followed in the experiments.

Experiment 9-B

Method. The method was the same as that used in 3-W.B, except that both ends of the wire were passed around the plate; the distal end of the femur of a growing dog was employed for the experiment, and the extra wire marker was omitted.

Result. Two hundred and sixty-seven days later, the total normal growth was 3.6 centimeters. There was 2.0 centimeters loss of growth in the bone with the wire loop. The distal epiphyseal plate had not contributed much to the increase in length, as 0.9 centimeters of the 1.6 centimeters of growth in the limb with the wire was from the proximal epiphyseal plate. There was some absorption about the wire, which may have allowed some growth from the lower plate.

Experiment 10-A

Method. A wire was passed into the distal epiphysis of the radius of a growing dog, through the epiphyseal plate into the diaphysis, to emerge on the medial side of the radius; the ends were twisted together under tension. A second wire was placed approximately parallel to the first; the ends of it were left free (Fig. 5).

Result. Three hundred and two days later, the normal growth was 3.9 centimeters. There was a loss of 2.3 centimeters of growth of the wired bone. Of the total growth of 1.6 centimeters, only 0.6 of a centimeter took place from the lower end, in contrast to 1.0 centimeter from the proximal epiphyseal plate. The articular end of the radius had become oblique, due to the greater restraining force on the ulnar side. The twisted wire was broken and the ends were separated during the limited growth.

Experiment 10-B

Method. A copper wire, 0.04 of a centimeter (one sixty-fourth of an inch) in diameter (No. 26), was passed transversely through the posterior part of the distal femoral epiphysis of a growing dog, obliquely across the epiphyseal plate, then transversely through the diaphysis near the dorsal surface. The ends of the wire were fastened by twisting under tension (Fig. 5).

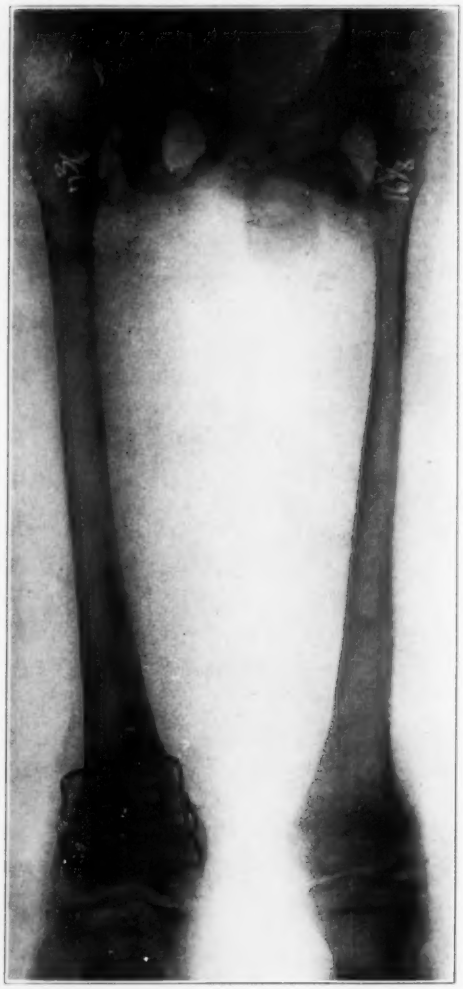

FIG. 6-A

Case 1. E. G. July 30, 1942, anteroposterior view, showing the wire as placed at the time of operation (March 27, 1942).

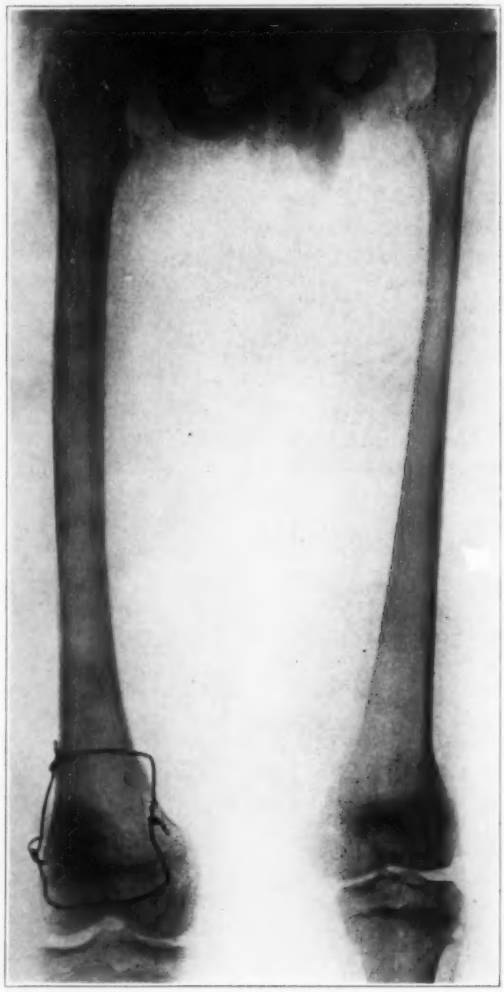

FIG. 6-C

July 12, 1944. Showing wire after it had broken and been refastened.

FIG. 6-B

July 30, 1942. Lateral view.

Result. Two hundred and eighty-seven days later, there was only 0.7 of a centimeter loss of growth. On examining the gross specimen, the wire was found to be on the dorsal surface of the bone. Since it had been passed through the diaphysis near the dorsal surface, it had pulled out, as growth took place, and thus had exerted very little restraining force.

Experiment 11-A

Method. A wire was passed through the periosteum of the epiphysis and directed vertically, so as to lie beneath the periosteum of this portion of the bone, the perichondrium of the plate, and the periosteum of the diaphysis through which it emerged a little above the plate. The ends were fastened together under tension (Fig. 5).

Result. Three hundred and one days later, there was no loss of growth. This shows that the operative approach to the plate did not disturb growth, and that there was little restraining force when the wire did not bind the epiphysis to the diaphysis.

SUMMARY OF EXPERIMENTAL RESULTS

In every experiment in which a wire loop was passed around the epiphyseal cartilaginous plate in the frontal plane, there was a definite loss in length growth of the bone.

If the wire loop became unfastened, the hindering force was not so great, and growth was retarded apparently in proportion to the remaining restraint of the wire to be overcome by the growing bone. The fact that some growth took place after the loop became unfastened shows that the epiphyseal cartilaginous plate maintains its potential length-growing properties while it is being mechanically restrained from length growth.

The retention of the wire, when applied to one side of the plate, will cause a greater decrease in growth on the side of the plate to which the wire is applied.

OPERATIONS ON PATIENTS

In view of this experimental evidence that length growth can be mechanically retarded by a loop of wire fastening the epiphysis to the diaphysis, we felt that it was warranted to attempt to control growth in children with discrepancies in leg length. However, it was recognized that a number of years must elapse before deductions were justifiable, because the growth period in human beings is so long and varies so much at different ages. In two of the patients, the wires have remained *in situ* for about two years. Even in this relatively short time, some interesting facts of practical significance are to be noted.

CASE 1. E. G., male, aged eleven and a half years, had had poliomyelitis on January 7, 1935. On March 4, 1941, one lower extremity was about five centimeters (two inches) shorter than the other.

On March 27, 1942, medial and lateral incisions were made opposite the lower end of the femur, and the epiphyseal cartilaginous plate was exposed. A stainless-steel wire, a little more than 0.12 of a centimeter (three sixty-fourths of an inch) in diameter, was passed through the epiphysis and the ends were turned proximally. A similar wire was passed through the metaphysis and the ends were turned distally. The two wires were then hooked together under tension (Figs. 6-A and 6-B). Roentgenograms were taken at certain periods for study of growth. On April 23, 1944, the loop was found to have broken. The wire was refastened on June 10, 1944. The findings are shown in Table I.

In checking these results, it is noticed that from March 4, 1941, to July 12, 1944, there had been 1.3 centimeters more growth on the short or affected side than on the normal. The growth discrepancy has been cut from 2.2 centimeters to 0.9 of a centimeter. The wire broke some time between September 23, 1943, and April 23, 1944, which was about one and a half years from the time of the operation. After breaking, the wire loop opened about 1.9 centimeters. If the wire had not broken, then there would have been 1.9 centimeters more restriction, and the difference in growth of the two bones would have been about 3.2 centimeters. If the wire had remained intact, the affected bone would have been about 0.9 of a centimeter longer than the normal femur.

In endeavoring to determine the cause of the break in the wire, three possibilities must be considered,—a defect in the wire, the pulling force of the epiphyseal plate, and

TABLE I

GROWTH OF FEMUR IN E. G.

Date	Normal Femur (*Centimeters*)	Short Femur (*Centimeters*)	Difference (*Centimeters*)
March 4, 1941 (before wiring)	43.2	41.0	2.2
March 27, 1942 (wiring)	....	....	....
July 30, 1942	44.1	42.5	1.6
September 23, 1943	46.4	45.1	1.3
July 12, 1944	47.6	46.7	0.9
Total growth	4.4*	5.7	

* Growth from wire to femoral head was 2.9 centimeters; growth from wire to lower articular surface was 1.5 centimeters. (The normal ratio of growth is about 30 per cent. from the upper femoral epiphyseal plate and 70 per cent. from the lower plate.)

TABLE II

GROWTH OF FEMUR IN S. B.

Date	Normal Femur (*Centimeters*)	Short Femur (*Centimeters*)	Difference (*Centimeters*)
March 30, 1942	37.8	34.6	3.2
April 1, 1942 (operation)	....	....	..
April 15, 1943	39.1	35.9	3.2
September 30, 1943 (wire found broken)	40.3	36.8	3.5
October 8, 1943 (wire refastened)	....	....	..
May 11, 1944	40.6	37.8	2.8
Total growth	2.8*	3.2	

* Growth from wire to femoral head was almost 1.6 centimeters; growth from wire to lower articular surface was 1.2 centimeters.

electrolytic reaction. There was no evidence of any defect in the wire, and it is hardly likely that there could be sufficient stress produced by the expanding force of a growing plate to cause the wire to break. It is possible that there was an electrolytic reaction which weakened the wire by corrosion and oxidation. It is known that electrolytic reaction is set up in metal at a bend. This is a possibility in the case under discussion.

CASE 2. S. B., male, aged ten years, had had poliomyelitis at the age of four and a half years. The left lower extremity was about 6.7 centimeters (two and five-eighths inches) shorter than the right.

On April 1, 1942, a wire loop was passed around the epiphyseal cartilaginous plate in the frontal plane. On September 30, 1943, a roentgenogram showed that the loop of wire had broken. On October 8, 1943, the ends were again connected with a piece of wire (Table II).

The measurements show that the two femora have grown about the same amount. In checking the results, it is noticed that the growth from the wire to the head of the femur is almost 1.6 centimeters; therefore, it would be anticipated that the growth would have been at least 3.6 centimeters from the lower epiphyseal plate. There has been only 1.3 centimeters contributed by the lower epiphyseal plate. Therefore, in spite of the fact that the wire had broken, there has been a considerable inhibition of growth. The total measurement of the two extremities is now almost equal in length, because of an additional lengthening operation on the tibia and fibula on the affected side. With an anticipated continued increase in length of the normal extremity, it seems advisable not to remove the wire, so that the growth discrepancies will not be too great at the termination of the growing period. The fact that growth took place after the wire broke, again shows that the restraining loop only temporarily inhibits growth, and does not destroy the normal power of proliferation of the plate.

SUMMARY OF RESULTS IN PATIENTS

In only two of the five patients upon whom wiring operations have been performed, has a sufficient time elapsed to draw any conclusions.

Because growth is relatively slow in man, determination of the practicability of the method of wiring the epiphyseal plate described herein must await the results obtained after a long period of time.

From the results obtained thus far on patients, there is definite evidence of growth retardation, and a continuation of the method seems warranted. The epiphyseal plate maintained its length-growing function, after being held in check by the wire for a considerable period of time. This is shown by the fact that following the breaking of the wire, which had been in place for a year, growth increased.

DISCUSSION

The methods of anticipating length of growth are, at best, speculative, because there are a number of factors that may change the rate and amount of growth. Although there are guiding tables of averages, the rate of abnormal growth cannot be calculated.

If growth can be controlled by alternately releasing and tying the wire loops, growth retardation may be instituted at a much earlier period, because, unlike resection of the epiphyseal plate which is permanent, the retardation is present only while the wire loop is in place. A metal band may give a wider surface of contact, and a removal band could be attached to the ends for controlling the fixation.

The wire around the plate did not produce any deformity, except when unilateral force was applied. Taking advantage of unilateral restriction, one may correct deformity following partial injury with arrest of growth on one side of the plate, by wiring the opposite side. It is also possible that such a corrective procedure could be applied in case of genu valgum or genu varum, by putting the wire around one side of the plate.

CONCLUSIONS

A wire encircling the epiphyseal cartilaginous plate in the frontal plane will stop length growth from that plate.

Growth may be controlled by a wire loop, by alternately stopping and allowing normal growth as the loop is tied or untied.

Length-growth equalization may be started at an earlier age.

Unilateral growth may be counteracted by a wire loop around the plate on the side of overgrowth.

The operation should not be performed until sufficient ossification of the epiphysis has taken place,—that is, after about eight years of age.

DISCUSSION

DR. JOHN ROYAL MOORE, PHILADELPHIA, PENNSYLVANIA: I wish to congratulate Dr. Haas on his original contribution. Growth arrest through epiphysiodesis has become a well-known and useful procedure in the equalization of extremity length. The principal difficulty is estimating the prospective length of the two extremities, or comparable bone involved. Dr. Haas has proposed a method by which we can arrest temporarily the growth of the more rapidly growing bone, then release it and have a resumption of growth. The illustrative cases are few, but very convincing. Temporary arrest until equalization has taken place would seem to be of very practical value.

DR. J. WARREN WHITE, GREENVILLE, SOUTH CAROLINA: I also want to congratulate Dr. Haas on this unique idea. There is a question in my mind, however, as to whether this delicate, highly differentiated tissue can stand the tremendous pressure which must be put on it to bring about the arrest of growth, and then start growing again after the pressure is released. That will be brought out in due course of time.

In the ten years prior to January 1, 1943, at the Shriners' Hospital in Greenville, 202 epiphysiodeses on 148 patients have been done. I became mildly interested in the procedure as a supplement to the shortening operation I had been doing for the previous five years. It has been a most interesting project.

One reason for my interest was the fact that, in fast-growing children, 25 to 50 per cent. of our gain in equalization was lost during the subsequent year or two after the shortening procedure. This I felt to be due to the growth stimulation of all the epiphyses of the very leg we wished to shorten.

In this group of "arrest cases", as I like to call them for short, eighteen femoral shortenings were done largely as supplementary measures. These, except for three performed in 1942, were all done in the first five years, thus showing that this procedure has been largely outmoded, except for adults or those children seen late in their growth period.

By and large, we have been well satisfied with our results. In our entire series, there have been few unfortunate developments, and most of these have resulted from overenthusiasm in doing multiple arrests early in the game. These required nine compensatory operations on the "short" side.

While we regret that these overcorrections have occurred, it shows that we have been attacking the problem aggressively, and you may be sure these particular cases have been carefully reviewed and will be reported.

This series of cases has added tremendously to the interest in the work of our end-result clinics, and in only ten or a dozen cases have we been unsuccessful in our follow-up.

Although we admit its immediate inaccuracy, we have employed exclusively what we call leg-length roentgenograms to record our discrepancies. The technique of this has been published, and has been found to be of much practical value. For several months a number of years ago, we took two exposures, and found that rarely did an error of more than 0.3 of a centimeter occur. It is so satisfactory, when reviewing a series of cases, to have tangible data to refer to, rather than records of tapeline measurements. We have averaged

well over six leg-length roentgenograms per patient, making well over 1,000 films in this series of 150 cases. This adds somewhat to the expense of the care of these patients, but we have felt that it is well worth it, and that, in this problem, accuracy in the recording of length discrepancies is of paramount importance. The error that exists in this method carries through the entire series, and tends to cancel itself.

The annual decrement in the discrepancies resulting from arresting growth at the distal end of the femur, preliminary report of which has been published,* is still holding good, and, regardless of the size or age of the individual during the growth period, we figure on 0.9 of a centimeter; at the proximal tibia and fibula we figure on 0.6 of a centimeter. Only two arrests have been performed at the distal tibia and fibula; but from these the annual decrement is considered to be 0.6 of a centimeter.

This means that the annual decrement is really less than the 0.9 and 0.6 of a centimeter mentioned, but as all figuring is based on the leg-length roentgenograms, this error also is cancelled.

In our calculations we have figured that girls grow until seventeen years of age and boys until eighteen, a point which explains our rather large number of overcorrections. Hereafter, we shall calculate that growth stops one year earlier.

In our series, the causes of the discrepancies were as follows: poliomyelitis, eighty-five, or 57 per cent.; congenital deformities including club-foot and arthrogryposis, 17 per cent.; osteomyelitis, 12 per cent.; and ankylosed hips from septic arthritis or tuberculosis, 12 per cent. As compensatory tilting of the pelvis in this latter group is impossible, much more accuracy is necessary in equalizing limb length, and over half of our compensatory arrests were done for the final refinement in those cases.

In no instance in these ten years have we had to correct varus or valgus deformities following the use of this technique, and in only two instances have deformities been noted. In one patient with arthrogryposis, who is now only thirteen years of age, deformity recently occurred; this will probably have to be corrected. We are not sure that our operation has caused the deformity. In another, deformity has resulted from a definite error in technique, but it did not show up until the boy had reached his full growth, and was not severe enough to require an osteotomy.

A great many orthopaedic surgeons have been hesitant about embarking on this problem, as most of the papers discussing it have, in my opinion, stressed too much the need of extreme accuracy in calculations. There are so many other variable factors in bone growth, over which we have no control, that I feel we are likely "to miss seeing the woods for the trees".

I would like to suggest that our Committee on Scientific Research establish a subcommittee on this discrepancy problem, as much needs to be done in working out a practical plan that can be followed easily by those whose chief interest is not in this particular problem.

Dr. Dallas B. Phemister, Chicago, Illinois: My experience with the growth-arrest operation for leg equalization has been similar to that of Dr. Wilson,—namely, that the surgeon usually errs on the side of conservatism, and, when the ultimate result is obtained, the limb in which growth was arrested is either of approximately the same length as the opposite one, or it is somewhat longer. Consequently, I believe that the fear of producing too much growth arrest, which is the greatest factor in causing surgeons to desist from doing the operation, is not justified by experience. Dr. White's report is the only one I know of in which several patients obtained too much growth arrest. I have had only one case in which there was failure of growth arrest on one side of the epiphysis, resulting in angulation of the limb. The condition was recognized early, and this side was fused by a second operation. If one follows the patient carefully, the failure of growth arrest on one side may be detected early, and a second operation may be performed. Consequently, the occasional occurrence of this complication should be no bar to the use of the operation.

Dr. Haas's work is evidence that he still possesses the power of original observation which has always characterized his publications. I would not be surprised, if much practical use is made of this procedure, both for length equalization and for the correction of the deformity produced by incomplete growth arrest.

Angulation of an extremity, from destruction of part of an epiphyseal cartilaginous plate by osteomyelitis or traumatic separation of the epiphysis, is a not uncommon condition which may be avoided, if the patient is carefully observed and an early growth-arrest operation is performed on the remaining open portion of the cartilaginous plate. It is an important use of the operation, and many serious deformities may thus be avoided.

Lieutenant Gerald G. Gill, Chickasha, Oklahoma: Dr. Haas is to be congratulated upon his finding of a method of temporarily retarding epiphyseal growth. This method may have a wide range of usefulness. However, two questions immediately present themselves and will undoubtedly be answered by Dr. Haas in due time. First, is the rate of growth normal after the removal of the wire which has retarded growth? Second, does the epiphyseal center thus retarded continue to grow as long as the normal center or does premature closure occur?

Dr. Wilson's paper very completely presents the difficulties which have beset those using epiphyseal

* White, J. W., and Warner, W. P., Jr.: Experience with Metaphyseal Growth Arrests. Southern Med. J., XXXI, 411, 1938.

arrest for the equalization of the length of the limbs in children. The errors in equalization found by Dr. Wilson, usually on the side of insufficient growth retardation, have been the experience of many surgeons. On the other hand, in a few instances, as pointed out by Dr. White, too much growth retardation has resulted.

In my opinion, these errors in prediction are, for the most part, caused by differences in sexual and skeletal maturation in children of a given age. In other words, children of the same chronological age often differ widely in their skeletal or sexual maturity. These variations may be determined by the assessment of the bone age by the method of Todd. It is my belief that these errors in equalization may be decreased, if, in each case, bone-age determinations are made.

Our knowledge of the growth of children is still very incomplete, and we should take every opportunity to gather exact data to complete our knowledge. For this reason, I believe that, in each case, metallic markers should be implanted in each bone, and that measurements should be made by roentgenographic methods, preferably scanography, so that the growth from each epiphyseal center may be measured. It follows that an accumulation of such data will increase our knowledge of the growth process, and will enable us to perfect our methods of prediction of growth. Only in this way will the use of epiphyseal arrest be placed upon a firmer footing.

DR. S. L. HAAS, SAN FRANCISCO, CALIFORNIA: It is believed that the growth in length is suppressed, but not permanently destroyed by the wire loop around the epiphyseal plate. If the roentgenograms, showing the wire loop intact for one and a half years, are compared with the two subsequent plates taken at intervals after the wire loop had broken, the widening of the loop and separation of the broken ends are seen. This is considered as sufficient evidence that the growth property of the plate was only temporarily inhibited while the wire was intact.

It is recommended that retardation by the wire loop be not attempted on a child under the age of eight years, because before this age the epiphyses consist of too much cartilage, and this may allow the wire to cut through and so permit growth to proceed.

All growth measurements are made on roentgenograms taken at a five-foot target distance.

LIEUTENANT COLONEL T. C. THOMPSON, WASHINGTON, D. C.: I have nothing to add, except that it seems our results are not so good as Dr. White's or Dr. Phemister's. We have no apology to make for our failures, except that the operations were done by a number of surgeons in a big teaching institution. Many were done by house officers under the direction of the attending men, so that the operative procedure may not have been as technically accurate as it should have been.

Dr. Haas is to be congratulated in getting arrest of growth without deformity in small animals.

COLONEL R. I. HARRIS, TORONTO, ONTARIO, CANADA: Dr. Haas has made the statement that among the methods which have been advanced

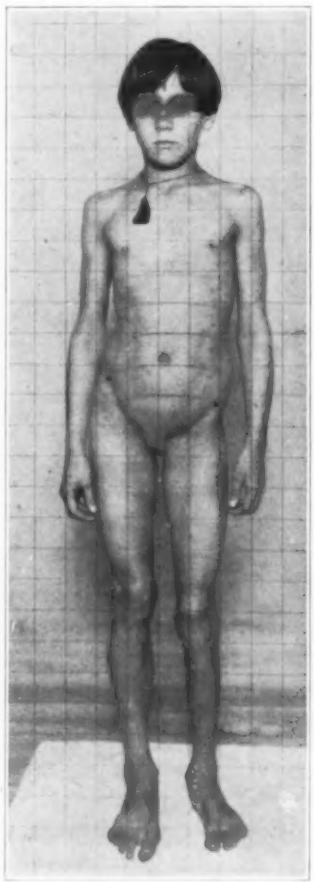

FIG. A

D. F., aged twelve years in 1930, had had poliomyelitis several years earlier. Her left lower extremity was 4.25 centimeters (1¾ inches) shorter than the right. A left lumbar sympathectomy was performed November 24, 1930.

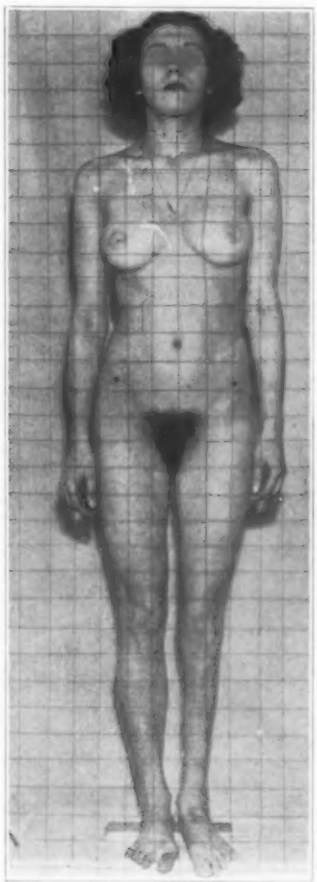

FIG. B

In 1937, when she was nineteen years of age, the left limb was 0.6 of a centimeter (¼ of an inch) shorter than the right. Most of the rapid growth, which resulted in the decrease in the discrepancy, occurred in the first three years after operation.

to produce equalization of limb length, lumbar sympathectomy is impractical, since the increase in limb length is uncertain and insignificant in amount. This is scarcely a fair assessment of the value of the procedure. It is our experience, based upon several hundred operations, that, when by lumbar sympathectomy the full vasodilator effect is secured and is maintained, enhancement in the rate of growth of the extremity always occurs. It is true that a wide variety of factors may act to impair the perfection of the result, but, under favorable circumstances, cessation of the progressive shortening can be counted upon, and, not infrequently, the shortness is overcome. The greatest gain which I have accomplished is 3.75 centimeters, as is shown in the accompanying illustrations (Figs. A and B). [See article by R. I. Harris and J. L. McDonald: The Effect of Lumbar Sympathectomy upon the Growth of Legs Paralyzed by Anterior Poliomyelitis. J. Bone and Joint Surg., XVIII, 35, Jan. 1936.]

J. L. McDonald, M.B., Toronto, Ontario, Canada: I am disappointed that Dr. Haas should dismiss the value of lumbar sympathectomy in patients with a short lower extremity—particularly with a short limb resulting from infantile paralysis—without further discussion.

Since the first lumbar sympathetic ramisection was performed by Colonel R. I. Harris at the Hospital for Sick Children, Toronto, in 1928, it has been repeated in over 400 cases, over 80 per cent. of these being in patients with a short limb resulting from infantile paralysis. In the first few cases, a lumbar sympathetic ramisection was performed, but during the past fourteen years all patients have had the sympathetic trunk and ganglia completely removed from the level of the second lumbar downward. We have found in these cases that the effect following sympathectomy has been sufficiently encouraging to continue the operation as a routine procedure in all patients showing a beginning difference in the length of the extremities following infantile paralysis. It is our practice to measure the length of the limbs in patients recovering from infantile paralysis, who have leg involvement, at frequent intervals; and, as soon as there is any evidence of difference in length, we carry out a lumbar sympathectomy on the affected side.

It is interesting to note that, following the 1937 epidemic of anterior poliomyelitis, the largest ever recorded in the Province of Ontario, we have had a relatively small number of patients showing shortening of the lower extremity. This again demonstrates that there are many factors involved in the etiology of the short limb besides disturbance of circulation.

Note: The paper on "Equalization of Leg Length with Comparison of the Results of Epiphysiodesis and Femoral Shortening" by Dr. Philip D. Wilson and Lieutenant Colonel T. Campbell Thompson, presented at the same session, has not yet been published.

CONCENTRIC ARTHRODESIS OF THE ANKLE JOINT

A Transmalleolar Approach *

BY ROGER ANDERSON, M.D., F.A.C.S., SEATTLE, WASHINGTON

Operations for fusion of the ankle joint are indicated for serious infections, flail joints, and especially traumatic arthritis. The joint sequelae of ankle fractures are frequently caused by incomplete reduction, but persistent ankle symptoms occasionally follow a perfectly reduced fracture. War injuries will further increase the number of cases of traumatic arthritis. Loss of cartilage or bone from compound fractures is prevalent among paratroopers and men in other branches of the Service, where the traumatic force is apt to be direct and explosive.

Since the disabling symptoms of traumatic arthritis can be eradicated by successful fusion, the importance of arthrodesis is apparent. The author believes that present-day procedures for arthrodesis leave much to be desired technically, and in the results obtained. First, there is the difficulty in visualizing and gaining working access to all compartments of the joint. Then, an even resection of the cartilage and subchondral bone from the entire joint, including the posterior portions, through the commonly advocated anterior approach, has its perplexing anatomical restrictions. It is exasperating to attempt through this approach, to resect the exact amount of bone for the desired degree of equinus, especially in procedures that call for a buttressing bone graft. To resect the convex talus and the concave tibia with an osteotome sufficiently to get full apposition calls for resection of unequal thicknesses of the subchondral plate. Then, if postoperative roentgenograms reveal improper angulation or poor contact, the bone graft hinders correction. Furthermore, the accepted anterior approach does not lend itself to the safe treatment of discharging suppurative lesions of the ankle joint.

Another cause of poor results, and an important one, is unsatisfactory immobilization. A circular cast, even though it extends to the upper thigh, will not absolutely immobilize the ankle in an ambulatory patient. As the swelling recedes and atrophy occurs, the cast becomes loose; and, as the crutch-ambulatory patient raises his foot off the floor, gravity continues to pull downward on the cast. Since a loose cast rests chiefly on the dorsum of the foot, a separation at the ankle joint occurs. Then, as the patient rests his foot on the floor, the ankle joint is forced together. Such alternate contact and separation is not conducive to bony ankylosis.

TRANSMALLEOLAR APPROACH

By the transmalleolar approach, the ankle joint can be easily resected, and the pitfalls of accepted methods may be avoided. The basis of this method is a bilateral approach to the ankle joint by subperiosteal resection of the malleoli. Once the malleoli have been removed, the entire tibiotalar articulation is accessible to the surgeon. Incomplete contact resulting from impingement of the malleolar tips is eliminated by resection of these structures.

CONCENTRIC ARTHRODESIS

The second step in the procedure is equally important and has been made possible by the bimalleolar approach. It consists in resection of cartilage and subchondral dense bone in such a manner that the resulting cancellous bone surfaces are concentric. Such resection can be conveniently effected by means of a special curved osteotome (Fig. 2).

*Demonstrated at the Scientific Exhibit, The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 22 to 26, 1944.

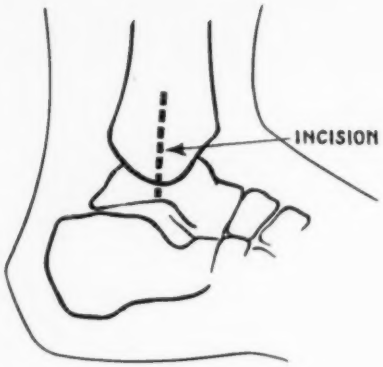

FIG. 1-A

Through a medial skin incision, the medial malleolus is subperiosteally resected. The malleolus may be discarded or may be cut up into small pieces and later used as grafts.

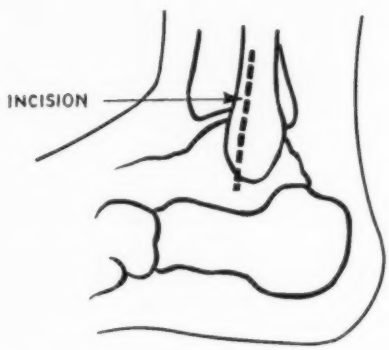

FIG. 1-B

Through a lateral incision, the lateral malleolus is also subperiosteally resected. If indicated, this malleolus may be likewise utilized.

FIG. 1-C

FIG. 1-D

Fig. 1-C: The resected ankle exposed.

Fig. 1-D: Since the curve of the contacting surfaces corresponds to that of the ankle joint, contact is complete, regardless of the degree of equinus.

FIG. 2

Fig. 2: Thin osteotome, the curve of which corresponds to the arc of the ankle joint. The two widths are illustrated in the foreview. The curve of the osteotome corresponds to the arc of a circle which has a diameter of 3.8 centimeters (1½ inches).

The concentrically resected joint permits maximum contact between the tibia and talus, regardless of the degree of equinus. If the postoperative position is not satisfactory, the foot can be placed in the exact amount of equinus desired, without loss of bony contact.

J. R. Moore has suggested to the author that additional stability can be gained by fusing the distal fibula to the tibia.

SUPPURATIVE ARTHRITIS

This method lends itself admirably to the treatment of suppurative arthritis. The approaches by resection of the malleoli provide excellent drainage channels. The technique has been successfully used for acute infections and for chronic cases where there has been extensive destruction of cartilage and adjacent bone, with abscess formation and profuse discharge.

In badly infected cases, in which discharge persists following the operation, the concentric resection may not result in bony union. However, this procedure provides a safe means of obtaining early closure of the compound wound, and usually the fibrous union

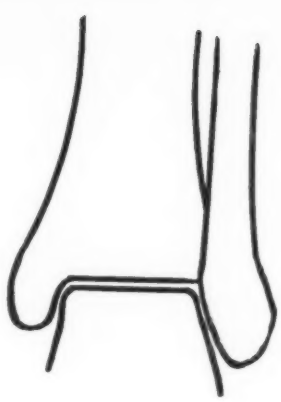

FIG. 3-A

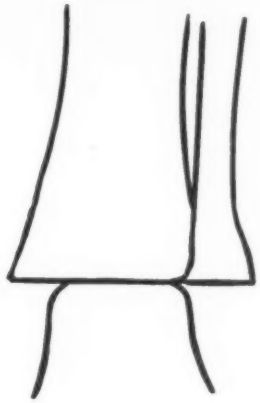

FIG. 3-B

FIG. 3-C

Fig. 3-A: Illustrates the relationship at the ankle joint before resection.

Fig. 3-B: Subperiosteal resection of the malleoli produces an apparent broadening of the ankle.

Fig. 3-C: The bases of the malleoli are reshaped, as illustrated. Excess bone may be placed around the ankle joint in the form of small grafts. Prominence of the anterior and posterior margins of the tibia may be similarly treated. Through the lateral incision, synostosis is produced on the anterior side between the fibula and tibia.

FIG. 4

Illustrates the site for the single transfixion pin used in the routine technique. The pin should be placed just superior to the incision.

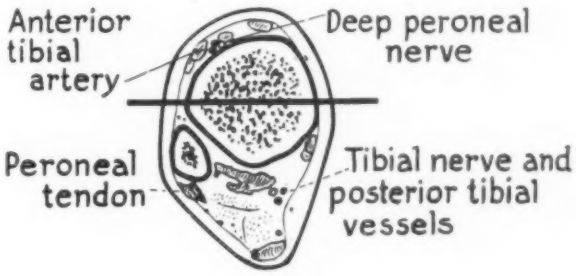

FIG. 5

Depicts the anatomical feasibility of placing the transfixion pin through the tibia.

FIG. 6

The castless method of immobilization is accomplished through the placement of two transfixion pins (or Kirschner wires) in the tibia, one through the os calcis, and one through the talus, in conjunction with medial and lateral fixation rods. While there are several advantages to the castless method, unfortunately the tarsal bones are so cancellous and relatively narrow that they do not tolerate transfixion pins as well as the long bones.

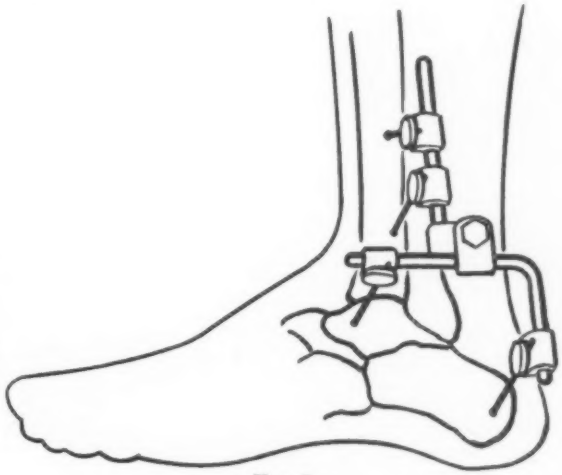

FIG. 6

that results is sufficient to give a pain-free and usable ankle. If symptoms should persist, a second concentric arthrodesis may be resorted to.

When it is obvious from the outset that amputation or an arthrodesis is inevitable, because of actual loss of bone or extensive trauma to the cartilage of the weight-bearing

FIG. 7-A

Illustrating the location of the transfixion pins for castless immobilization.

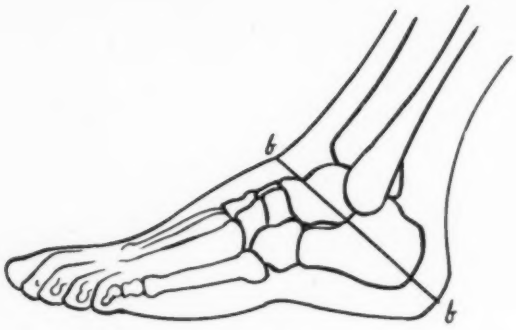

FIG. 7-B

The line *b-b* denotes the level at which the cross sections, shown in Figs. 7-C and 7-D, were made.

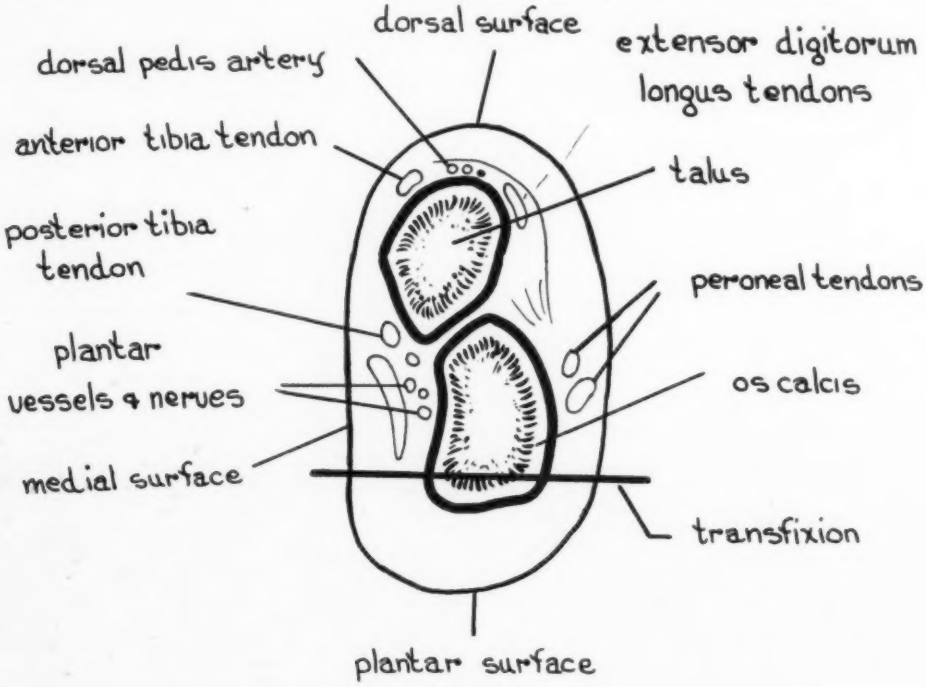

FIG. 7-C

Cross section of the foot made at level *b-b*. Shows the placement of the os calcis transfixion pin.

surfaces, or when the loss of soft tissues prevents closure of the wound, and infection is probable because of the soft-tissue damage, the joint should be arthrodesed immediately by the technique here described, except that the incisions, lengthened if necessary, may be left wide open.

OPERATIVE TECHNIQUE

1. A longitudinal incision is made over the medial malleolus which is then resected subperiosteally. The cartilage and subchondral bone of the talus and the tibia are removed with a curved osteotome.

2. The lateral incision is made as illustrated in Figure 1-B, and the external malleolus is resected subperiosteally.

3. The removal of the remaining cartilage and subchondral bone of the talus and the tibia is then completed.

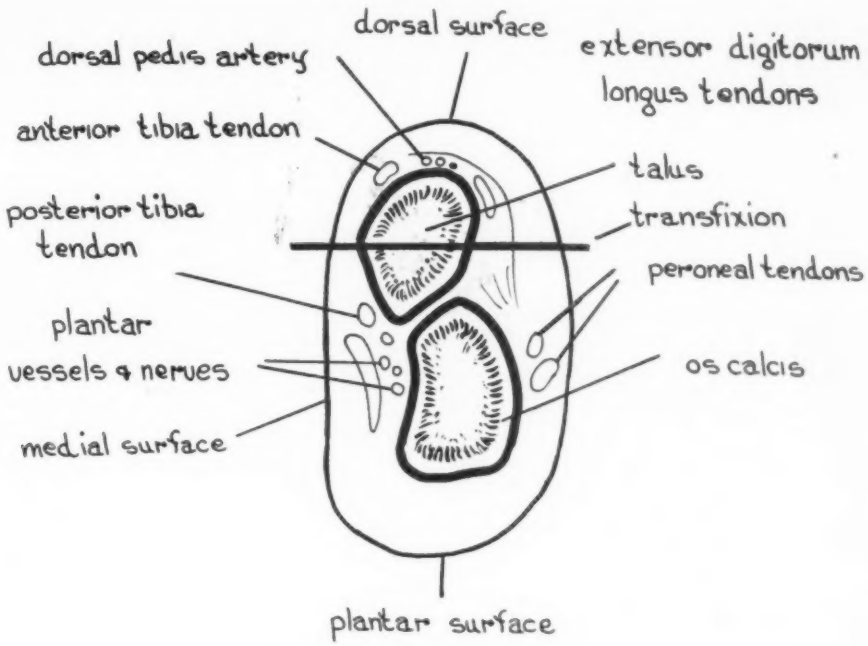

FIG. 7-D

Shows the transfixion pin through the talus.

In resecting the joint, the osteotome should be held parallel to the tibial or talar articular surface. Care should be taken that all the dense subchondral bone is removed, since union is quicker and surer with cancellous-bone contact. Furthermore, by selecting the angle at which the osteotome is held, correction of a varus or valgus deformity can be

FIG. 8

Mr. B. H., depicting method of castless immobilization. An elastic cotton bandage was wrapped around the leg before the fracture units were applied.

FIG. 9-A

Mrs. M. W. had been injured one year before the first examination. Even with her weight of nearly 200 pounds, she had been trying to walk. Arthrodesis was performed September 1, 1942.

FIG. 9-B

Final roentgenograms taken on February 3, 1944, nearly a year and a half later. Because of her weight, the ankle had been placed in slight valgus. (The author's clinical experience has shown that heavy patients with small feet do better, if the ankle is fixed in slight valgus.)

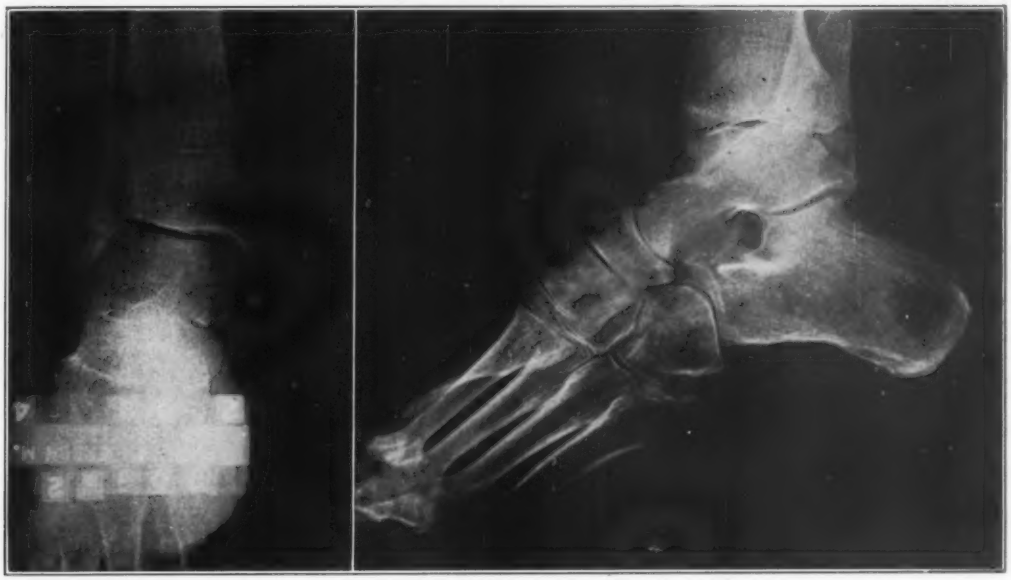

FIG. 10-A

Mrs. R. G., February 12, 1943. A fracture two months before had been treated with adhesive strapping, and the patient had been on crutches most of the time since. The symptoms were out of proportion to roentgenographic findings.

FIG. 10-B

May 4, 1944, fourteen months after operation. Note the formation of the new external malleolus. At this time, the patient walked without a limp.

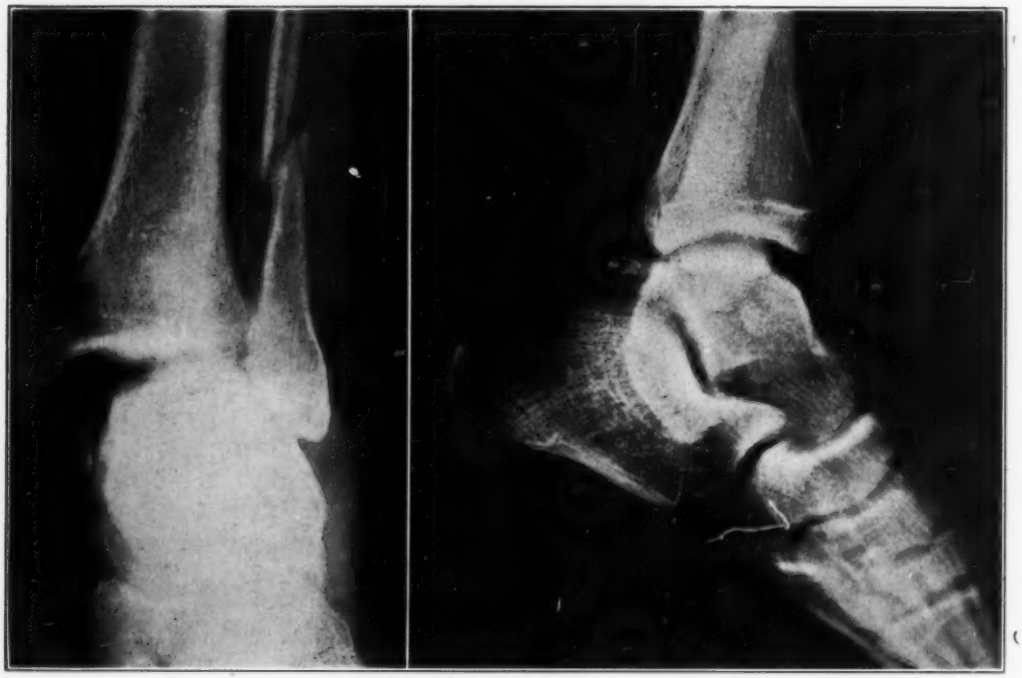

FIG. 11-A

Mr. K. P., September 6, 1943, a month after the accident. He had been treated elsewhere for the extensive, compound fracture-dislocation of the ankle, severance of the tendons, and very deep soft-tissue injury, with large third-degree gasoline burns. When he was referred to us, there was marked infection, and the reduction could not be maintained.

The joint was resected through the large, open, compound wound on the medial side, and several inches of the flexor hallucis longus, flexor digitorum longus, and posterior tibial tendon was resected. The lateral incision was left open, so as to supply through-and-through drainage. The wounds healed, in spite of a large area (several inches in diameter) of persistent skin defect.

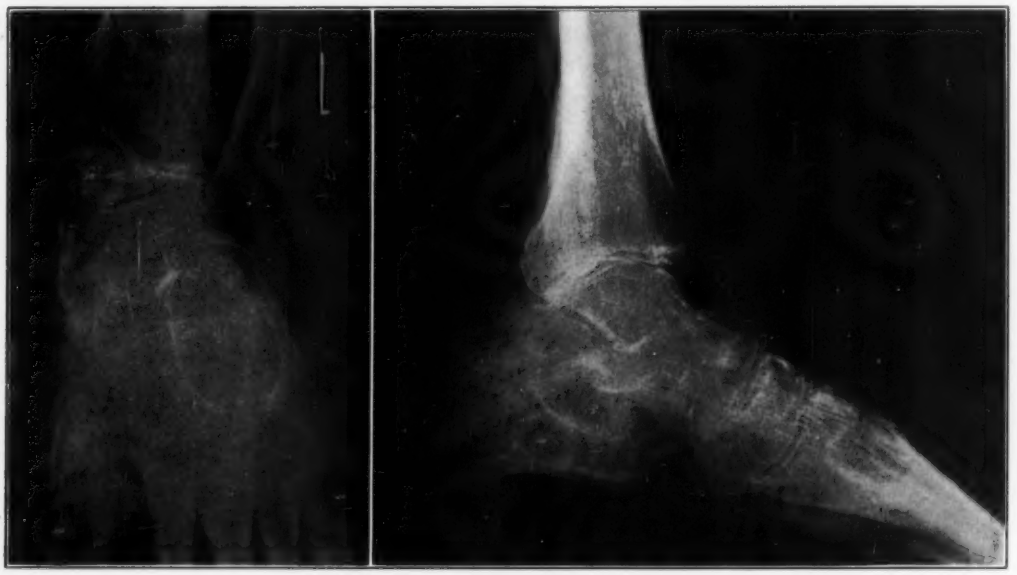

FIG. 11-B

March 22, 1944, six months later. As occasionally happens, when there is an active infection, the roentgenograms reveal only fibrous fusion. However, clinically, there is union. Although it is desirable to fuse the ankle in a position of slight valgus, there is a little too much valgus in this case. This will be corrected when a subtalar fusion is performed after the patienth as recovered from a skin-grafting operation on the medial side of the leg, which was performed May 3, 1944.

FIG. 12-A

FIG. 12-B

FIG. 12-C

Fig. 12-A: Mrs. A. B., aged fifty-four years, sustained a compound fracture-dislocation. A good reduction had been obtained elsewhere on June 28, 1942, but the cast had failed to hold the fragments. On first examination (July 8, 1942), there was dislocation and a large amount of discharge.

Roentgenogram taken on August 15, 1942, revealed soft-tissue swelling and osteomyelitis of the malleoli, talus, and a large portion of the tibia. The fibula had not united and showed no evidence of callus formation. An operation was performed on August 20, 1942, in the presence of a profusely discharging wound and interosseous abscess formation.

Fig. 12-B: Lateral view following operation. There was so much infection and involvement of the soft tissues around the ankle that the transfixion pin anchoring the cast was inserted through the superior tibia. The necessity of resecting so much infected bone resulted in some shortening, and a

(FIG. 12-B *continued*)

greater degree of equinus than illustrated is called for. The desired equinus was subsequently obtained, as shown in Fig. 12-C.

Fig. 12-C: April 10, 1944, nearly twenty months after operation. In spite of the open and grossly infected ankle joint at the time of operation, bony ankylosis has resulted; the fibula has now united; and the wounds have remained healed for nearly a year.

FIG. 13-A

Mr. S. A., May 12, 1943, nearly two years after injury. The patient had sustained an extensive fracture, which had been satisfactorily reduced elsewhere. However, symptoms developed, and his doctor performed an arthrodesis through the usual anterior approach. The roentgenograms reveal that fusion did not result.

readily achieved. Before closure, a close study must be made to be sure that there is no varus or valgus angulation as the talus contacts the tibia.

4. Through the lateral incision, the adjacent surfaces of the tibia and fibula are exposed anteriorly, and are denuded by removing intervening tissue; the resulting space is filled with bone chips obtained from the shafts, so that synostosis will result.

5. The remaining portion of the base of each malleolus is rounded. To stimulate early osteogenesis, little flaps of bone may be raised with a small osteotome from the contiguous surfaces of both tibia and talus. Contact and position are checked and altered as required. The resected malleoli may be cut into small pieces and placed as reinforcing grafts.

6. A fifteen-centimeter (6-inch) Steinmann pin, 0.3 of a centimeter ($\frac{1}{8}$ of an inch) in diameter (or Kirschner wire with tautener), is placed through the distal tibia at a level approximately five centimeters superior to the ankle joint. Small dry dressings are applied over the pin, and narrow, sterile sheet wadding is used to hold the dressings. A lock nut is attached to each end of the pin to facilitate firmer incorporation in the cast.

7. The cast is applied from toes to below the knee, incorporating the pin.

IMMOBILIZATION

By either the cast or castless techniques, such complete immobilization of the ankle joint is supplied that patients without compound fractures may be crutch-ambulatory.

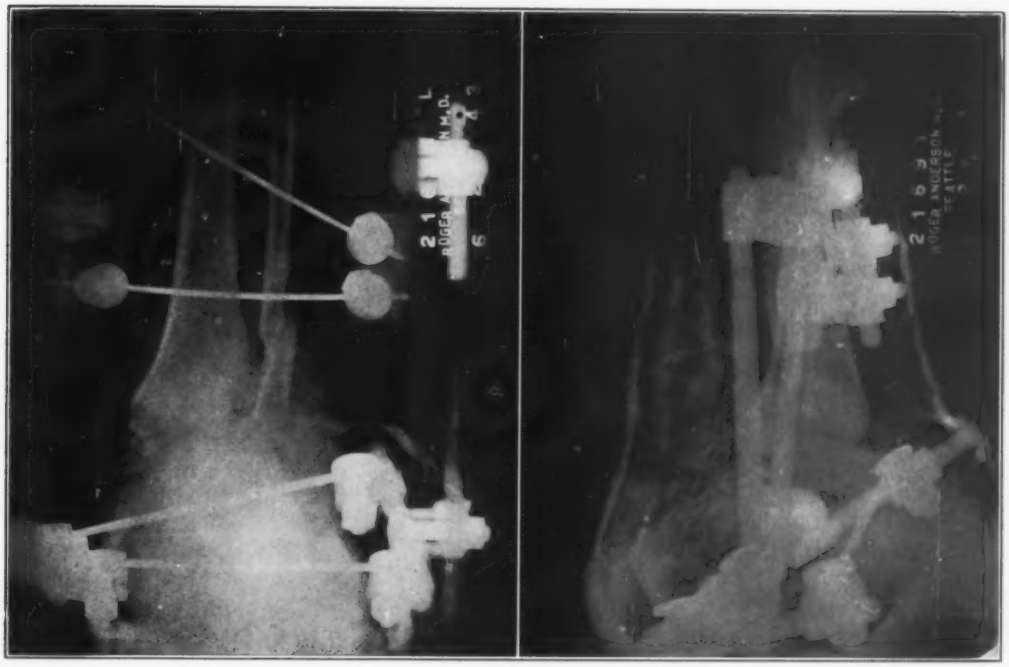

FIG. 13-B

June 21, 1943. Arthrodesis by the method described was performed on May 22, 1943. The castless technique was employed, with a plaster bandage over the fixation rods to hold the dressings in place.

FIG. 13-C

March 31, 1944, ten months after operation. Roentgenographically there does not appear to be a solid bony union. The patient was complaining of pain in the subtalar joint, and on May 24, 1944, this joint was resected and fused. The ankle joint was exposed through the same incision, and it was found that union was solid between the talus and the tibia. There was slight motion at the tibiofibular junction which had not been surgically fused previously. It was fused at the second operation.

Plaster fixation calls for insertion of one transfixion pin, either through the distal tibia just above the incision or through the superior tibia. The circular cast extends from below the knee to the toes, and in it the pin is incorporated. As the cast is being applied, pressure is uniformly exerted on the sole of the foot, and the convex talus is pressed into the concave tibia for maximum apposition. Immediately after the plaster sets, roentgenograms will indicate any needed correction, which may be made at once, or if the position is fair, may be postponed until the stitches are removed.

Castless immobilization is obtained by placing two transfixion pins (or Kirschner wires) through the distal tibia, one through the os calcis, and one through the neck of the talus. The four pins are then connected with fixation rods, while the talus is being forced into contact with the tibia. The talus and other tarsal bones do not tolerate transfixion pins well, especially if they are not firmly fixed or if there is some loss of bone salts from disuse. Therefore, this is not advocated as a routine procedure; when it is used, it may be advisable to use some plaster or plastic bandages as additional reinforcement.

The transfixion pins should be placed exactly as indicated, but, if the skin in the region of the ankle is scarred or unhealthy, or if a sinus is still present, the tibial transfixion pin may be placed through the superior tibia.

COMMENTS

The skin incisions should be placed as illustrated, so as not to interfere with the subsequent placement of the transfixion pins.

All efforts should be made to keep the foot in 5 to 8 degrees equinus and in slight valgus. If postoperative roentgenograms reveal loss of apposition, correction can be secured by removing a thin transverse section of the cast at the level of the ankle and forcing the bones together.

Early ambulation, with active knee and toe motions, is of paramount importance, since prolonged immobilization invites phlebitis, muscle and bone atrophy, and diminished blood supply.

In growing children, the transmalleolar approach supplies a practical route for resection of the ankle joint without injury to the epiphyses.

SUMMARY

The transmalleolar approach to the ankle joint, with excision of the malleoli, provides surgical access to the entire joint under direct vision.

Resection of the joint with an osteotome, the curve of which conforms to the arc of the ankle joint, assures an exact osseous approximation, regardless of the degree of equinus.

Subperiosteal resection of the malleoli permits direct contact between the talus and the tibia.

Resection of the malleoli and the rounding of their bases make a narrow and shapely ankle.

Bilateral incisions supply a means of obtaining simultaneously drainage of the joint and fusion in septic compound fractures, even in the active stage of infection.

Immobilization by means of transfixion pins (or Kirschner wires), fixed by either the cast or castless methods, is so positive and complete that early crutch ambulation can be permitted with safety.

ARTHRODESIS OF THE ANKLE JOINT FOR OLD PAINFUL FRACTURES *

BY HALFORD HALLOCK, M.D., NEW YORK, N. Y.

From the New York Orthopaedic Dispensary and Hospital, New York

Arthrodesis is an effective means of relieving the pain and disability that often arise from old ankle fractures. This fact is established by an end-result study of thirty-eight of the forty-seven patients who had an ankle fusion for this condition at the New York Orthopaedic Hospital from January 1928 to April 1943. Nine of the forty-seven had follow-up examinations less than one year after operation, and have therefore been excluded from the end-result group. They are included, however, in the preoperative and operative study. One patient had bilateral arthrodesis, making a total of forty-eight ankle fusions. Twenty-two of these cases were reported by Kimberley in 1936.[1]

This is not a large number of cases for a period of fifteen years. Many more patients than this were seen in the Dispensary complaining of painful ankles following fractures, 216 in the five-year period from 1928 to 1933, according to Kimberley; but, in many, conservative measures probably afforded sufficient relief, and, in some, surgery was undoubtedly not accepted when advised.

The group of patients operated upon, therefore, represents the more severe type of case, or the one in which conservative measures have failed. The pathological changes seen in these joints at operation make the surgeon appreciate the potentialities of surgery, and the limitations of physical therapy and support. Better treatment of the original fracture will probably mean less need for subsequent treatment or surgery; but even with accurate anatomical reductions, which can be secured in most instances only by meticulous open reduction, defects of the articular surface may persist, and a painful arthritis may ensue.

All but three of the forty-seven patients who were operated upon had more or less severe malunited fractures affecting the ankle joint; and in these three, although their fractures had healed in good alignment, a pronounced arthritis had developed. One had additional deformity caused by partial epiphyseal arrest, brought about by the original injury.

The patients complained chiefly of pain and limitation of function. Their ages at the time of operation ranged from sixteen to fifty-six years; the average age was thirty-eight; the time of operation after the original injury varied from one month to twenty-one years; the average time was three and seven-tenths years. One patient, whose ankle was fused one month after fracture, had sustained multiple injuries in a thirty-five-foot fall, including a comminuted fracture of the distal fourth of the tibia involving the ankle joint, with a forward and upward dislocation of the talus. It was obvious that no treatment other than an arthrodesis would yield a satisfactory result. Fusion was obtained within six months, and at the last examination, three years later, the patient was free from pain and walked normally with or without shoes.

OPERATIVE TECHNIQUE

The ankle joint is exposed through an anterior longitudinal incision midway between the malleoli. A tourniquet is used above the knee. The tendons of the extensor digitorum longus are retracted laterally and those of the tibialis anterior and extensor hallucis longus, together with the dorsalis pedis vessels, are retracted medially. The periosteum of the tibia and the capsule of the ankle joint are divided longitudinally, and are reflected

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 1, 1944.

sufficiently to expose the anterior borders of both malleoli and their articulations with the sides of the talus. The articular cartilage is removed from the superior, medial, and lateral surfaces of the talus, from the tibia, and from both malleoli. Mild or moderate degrees of deformity can now be corrected by removing certain portions of bone. Sometimes it is also necessary to perform osteotomies of the malleolar portions of the tibia and

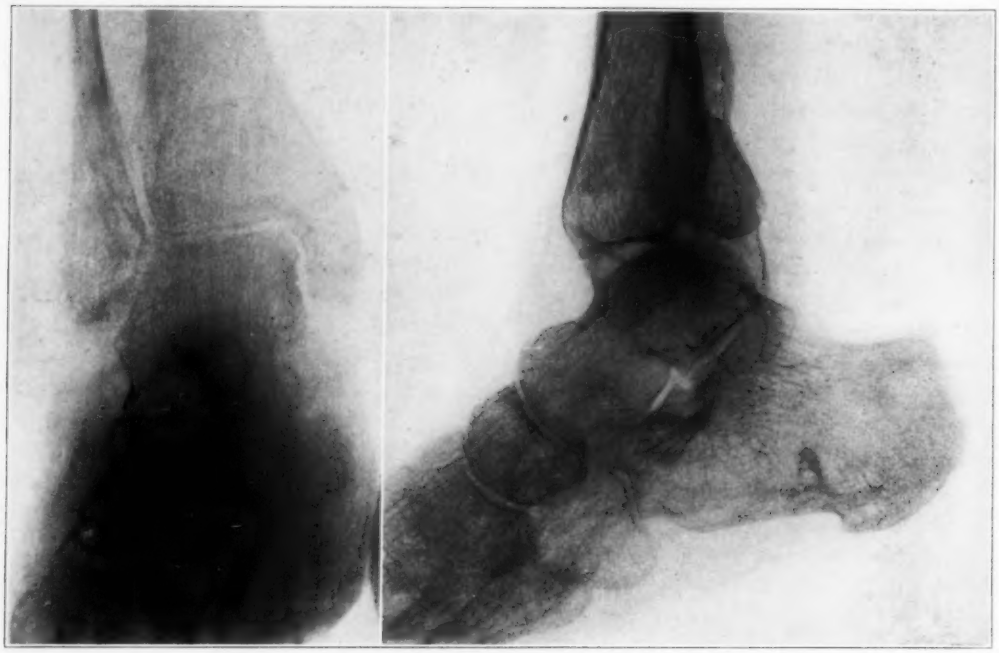

FIG. 1-A

A. McG. Preoperative condition four months after fracture.

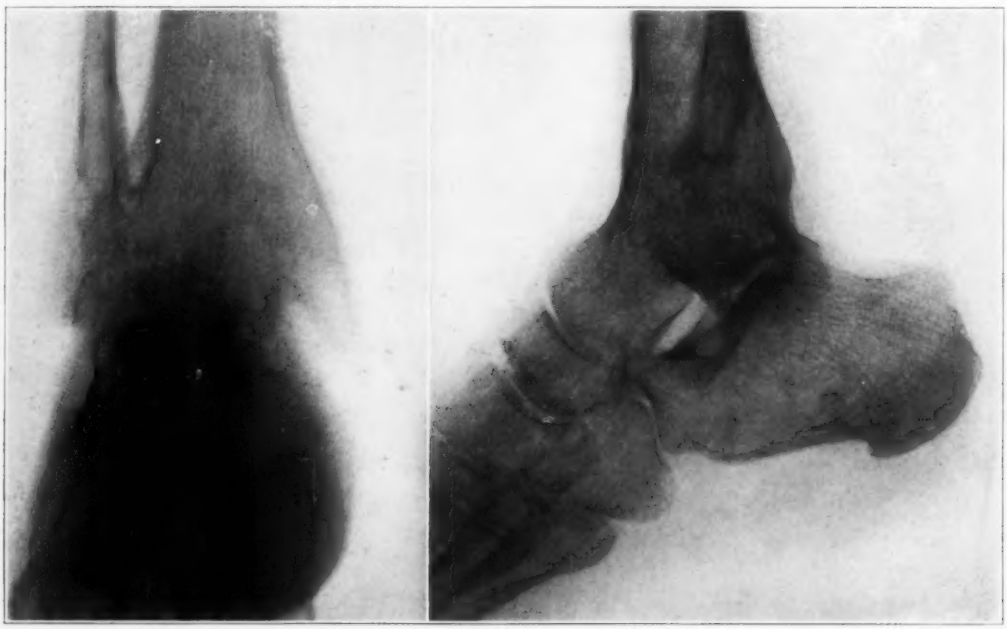

FIG. 1-B

Ten years after ankle fusion. There is no pain, and patient can be on her feet all day and walk as far as she pleases. The ankle is fused in 10 degrees of equinus.

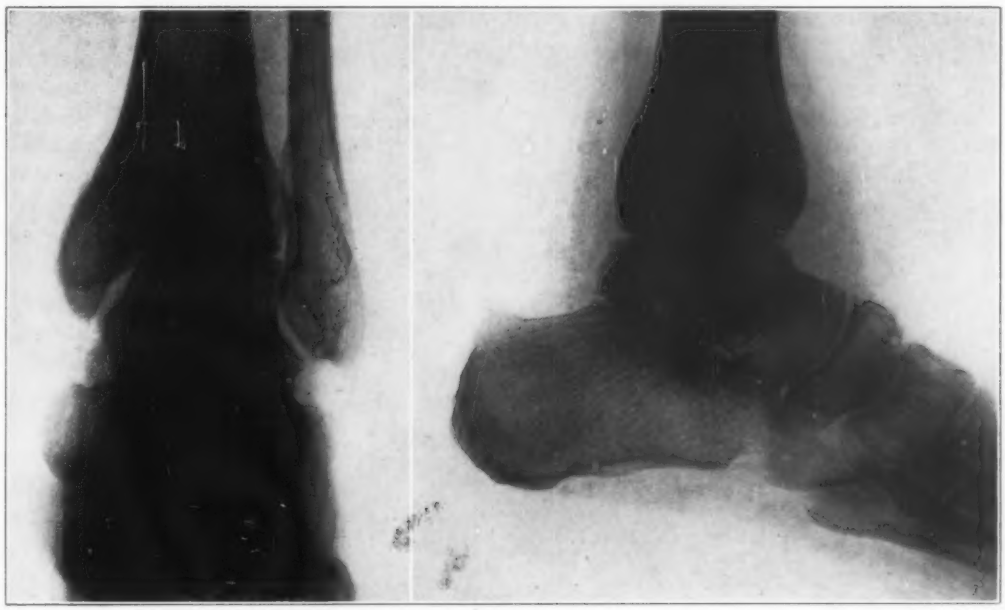

FIG. 2-A

H. F. Preoperative condition fifteen months after fracture. Subtalar arthritis is present.

FIG. 2-B

Eight years after ankle fusion. Subtalar arthritis is more marked. There is fatigue in the foot and the ankle after walking ten blocks, and pain in bad weather. Subtalar joint mobility is limited two-thirds by stiffness.

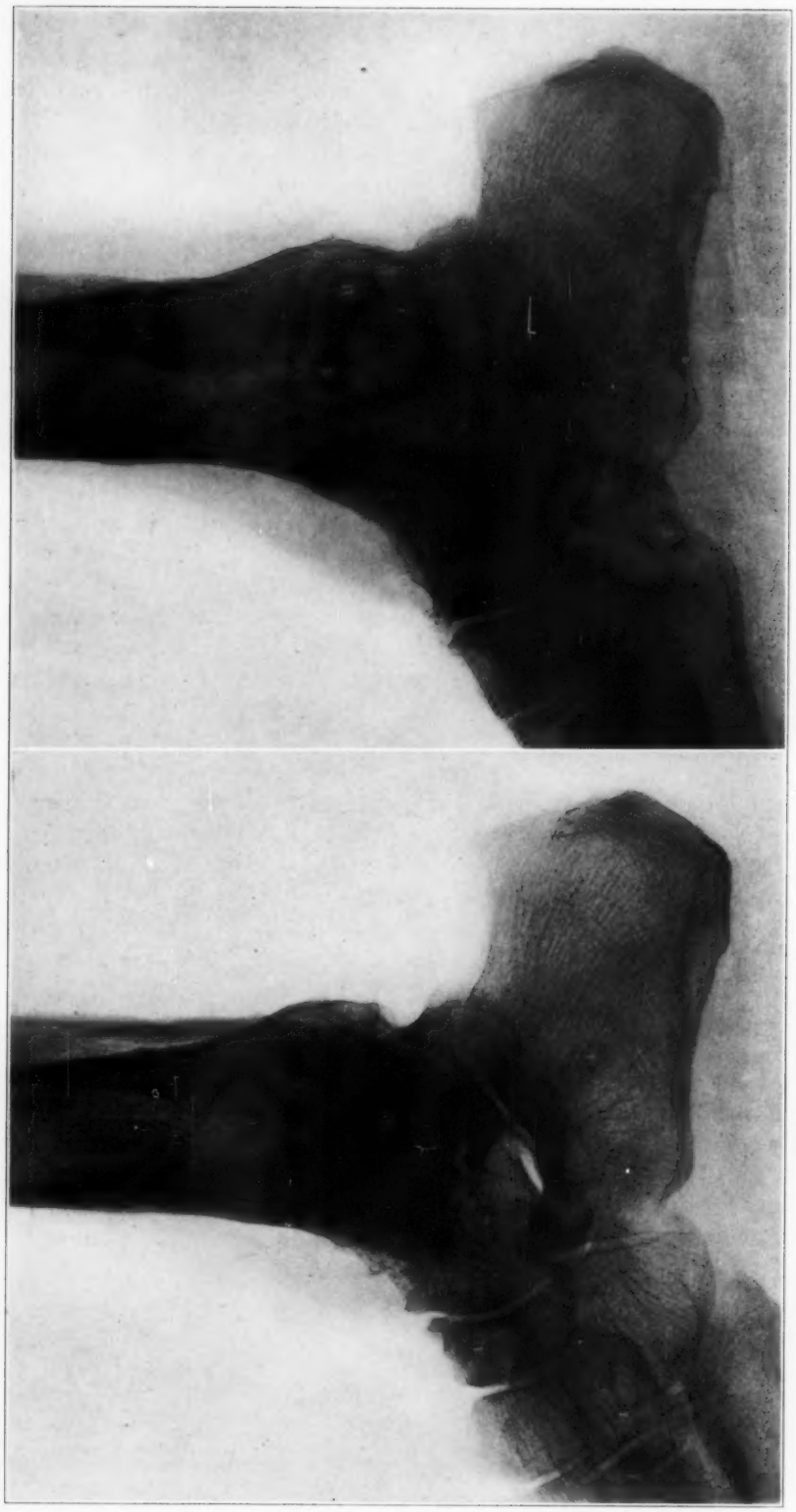

FIG. 3-A FIG. 3-B

Fig. 3-A: S. C. Subtalar and talonavicular arthritis two years after ankle fusion. This was present before operation but not quite so marked.
Fig. 3-B: Seven years after triple arthrodesis because of pain. Lipping is now present dorsally at the cuneonavicular joint. Patient has been relieved of most of her preoperative pain and is on her feet all day, doing housework and cooking.

fibula or of the lower portion of the fibula, in order to obtain adequate correction and to restore the foot to a proper weight-bearing alignment with the leg. Occasionally lengthening of the tendo calcaneus may be required to aid in correcting equinus.

The opposing bony surfaces are then "fish-scaled" by turning down attached chips of bone and interlacing them, if possible, across the joint interval. Additional bone chips are removed from the lower portion of the tibia and are packed into the spaces between the talus and the tibia, and the talus and both malleoli. Chips are also laid across the joint anteriorly. (In five patients, bone grafts or pegs were employed as well.) The wound is closed in layers, and after the deep sutures have been placed, the tourniquet is removed. A plaster cast is applied, extending above the semiflexed knee, with the foot in 10 degrees of equinus.

A plaster boot for walking is applied after six weeks, and usually the arthrodesis is strong enough to bear weight without support after twelve weeks. Once the cast has been removed, physical therapy is employed to decrease swelling, to rehabilitate the muscles, and to promote compensatory mobility in the subtalar and tarsal joints. If arch strain occurs, a support may be used for as long a time as is necessary.

The position of the ankle is checked by roentgenograms after operation. The degree of equinus is determined by drawing a line from the inferior surface of the calcaneus to the plantar margin of the first metatarsal head, and a second line through the longitudinal axis of the tibia, and measuring the angle of their intersection. If the position is not satisfactory, the cast is cut posteriorly above the heel, a section is removed over the ankle joint anteriorly, and the foot is brought up to the proper position. If the ankle is to be wedged downward, the section of plaster is removed posteriorly. This should be done, when necessary, five to ten days after operation. One or two wedgings do not seem to interfere with fusion, but it is conceivable that more might do so.

OPTIMUM POSITION FOR FUSION

An equinus of about 10 degrees is considered generally to be the best position for a fused ankle, as with this amount and with the range of compensatory mobility that usually develops in the subtalar and tarsal joints, walking is easy and essentially normal with or without shoes. When an ankle is fused at right angles or less, difficulty is experienced in advancing over the foot, and an undesirable and awkward heel gait results. With more than 15 degrees of equinus, increased stress and strain is brought to bear upon the metatarsal region, and barefoot walking becomes more and more difficult. Weight is borne either entirely on the ball of the foot, or on the heel and sole by external rotation and abduction of the hip, and hyperextension of the knee. With shoes on, however, a patient with excessive equinus may not exhibit an abnormal gait, because of the compensating effect of a high heel.

CORRECTION OF LATERAL DEFORMITY

If lateral deformity of the ankle is present to a degree sufficient to alter considerably the weight-bearing line through the leg and foot, correction should be obtained. In mild or moderate degree, this can be accomplished by the removal of appropriate wedges of bone with or without malleolar osteotomies; but when the deformity is severe, it is probably better to fuse the ankle in the deformed position, and then later to do an osteotomy of the tibia and fibula through the cancellous bone above the joint. At this level, the fragments are controlled fairly easily, and there is less danger of delayed union or nonunion than when the bones are divided at a higher point. Supramalleolar osteotomy was not done in this series; but, on several occasions, it has been performed, without fusion, to correct deformities of the lower end of the tibia without other ankle-joint disorder; and, in one case, with joint involvement, prior to probable fusion. This osteotomy was planned for in one case, to follow arthrodesis, but has not been performed,

because the patient has done well following fusion alone, and apparently has compensated adequately for the malposition.

An attempt to correct the lateral deformity at the time of fusion was made in fourteen, or 29.2 per cent., of the forty-eight ankles. This was not always successful, and often correction was found to be difficult and sometimes impossible. For this reason, it would be well to study carefully cases with marked deformity, from the point of view of obtaining proper alignment after fusion by supramalleolar osteotomy.

COMPLICATIONS

Complications were few in number. There were no deaths from operation. One patient died from a cardiac condition four years after operation. A pressure ulcer developed over the medial malleolus in one patient, a hematoma developed in another, and maceration of the wound occurred in two.

There were three wounds infected with the staphylococcus aureus. One was superficial and healed readily.

In the second case, the infection involved the ankle joint, and extended into the talonavicular joint, with resultant ankylosis of that articulation. This patient had had a compound fracture one and a half years before, with drainage for seven months. Now, three years later, he has a clinically fused ankle in 10 degrees of equinus, and a stiff foot in mild varus. He is on his feet at work all day. There is no drainage, but occasionally he has pain in the foot at the end of the day.

In the third case, infection occurred after a refusion of the ankle. Eventually a sequestrectomy was necessary, and the most recent roentgenogram does not show bony union. The ankle, however, is solid clinically, and there is no drainage.

RESULTS

Thirty-eight of the forty-seven patients have had follow-up examinations from one to sixteen years after operation. The average time was four and four-tenths years. As one individual had bilateral fusion, thirty-nine operations are represented in this end-result group.

Arthrodesis

Bony union was secured in thirty cases, or 77 per cent.

Failure of fusion definitely occurred in four. This is a known failure of 10 per cent. Three of these patients have been reoperated upon, with success in one, failure in another, and a doubtful result in the third. The last was the patient in whom an infection developed at reoperation. The fourth patient has been advised to have another operation, but has declined, although she is having pain.

In five patients, or 13 per cent., arthrodesis may be doubtful. In two of these, final roentgenograms at nine months did not demonstrate fusion; but arthrodesis is clinically present three and four years later, and symptoms are absent except for occasional pain at the end of the day in one. In three patients, roentgenograms at thirteen months, fourteen months, and three years, respectively, revealed doubtful fusion. It may be present, however, as these three individuals are free from pain and have clinically solid ankles.

If these five cases in which the presence of fusion might be questioned are added to the four in which arthrodesis did not occur, a possible failure of 23 per cent. is obtained.

Pain

All the patients except one had pain preoperatively to such a degree as to cause disability and to force them to accept surgery for its relief.

Postoperatively, twenty-two, or 56.4 per cent., are completely free from pain; eight, or 20.5 per cent., occasionally complain of slight pain in the foot or ankle (as at the end of

a long day or in bad weather); and eight, or 20.5 per cent., have considerable pain. In one patient, no note was made with regard to symptoms; but the roentgenogram reveals a doubtful fusion, and it is possible that this patient may be having pain, although the ankle feels solid clinically.

Adding the first two groups, thirty ankles, or 76.9 per cent., have been completely or almost completely relieved of pain.

The patients who are complaining of pain have been studied in an effort to discover the reasons for the persistent symptoms. In three of the eight, who occasionally have slight pain, no apparent cause has been found; late roentgenograms in two cases are not

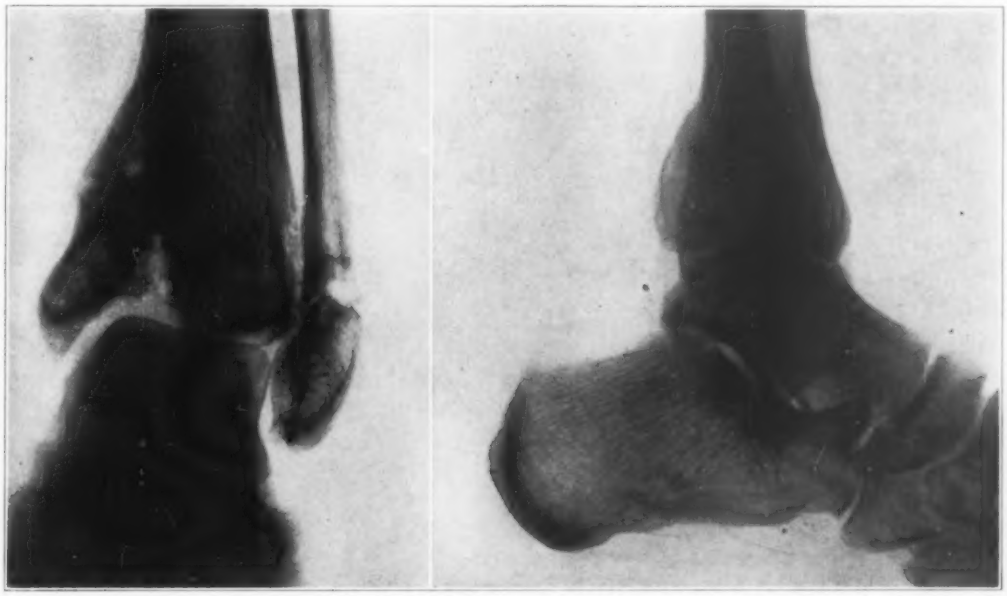

FIG. 4-A

W. D. Preoperative condition one year after fracture.

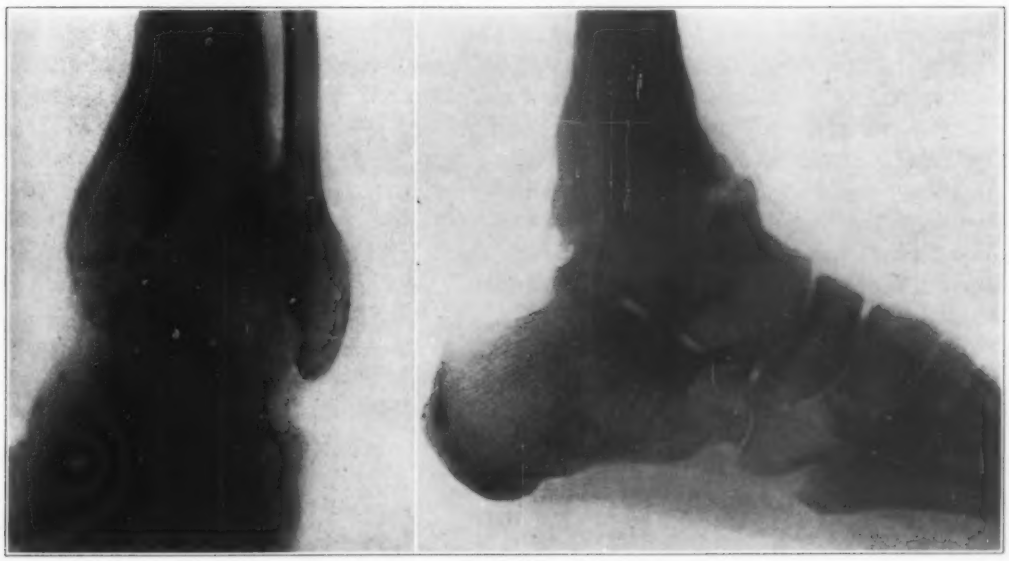

FIG. 4-B

Three years after operation. Fusion is doubtful roentgenographically, but may be present through a small area posteriorly. Patient is free from pain and is on his feet all day.

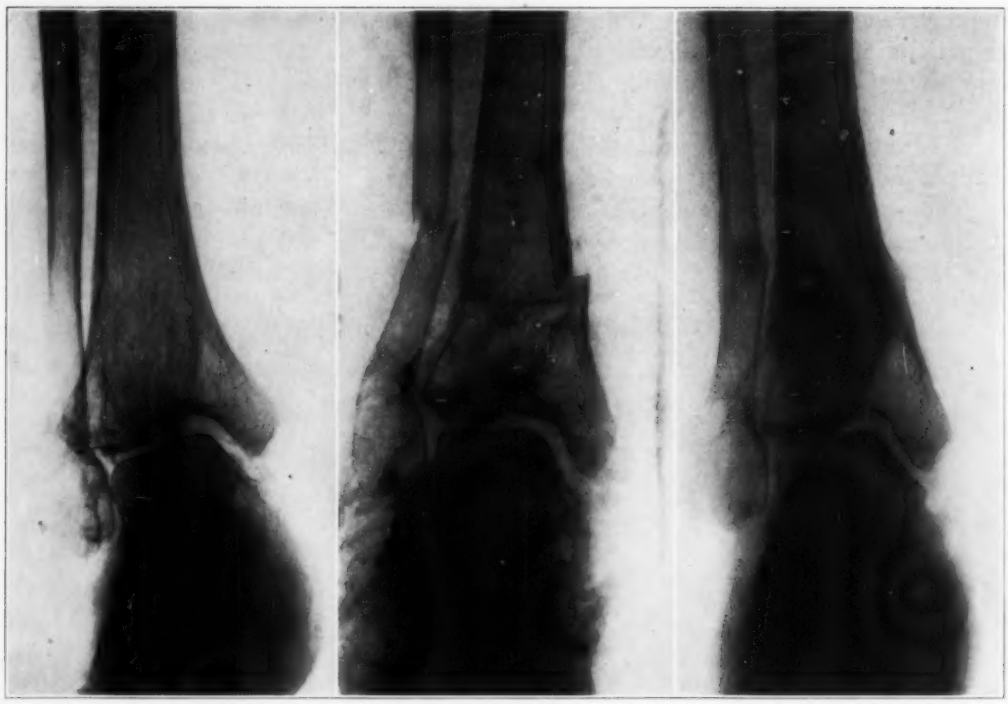

FIG. 5

Illustrating the use of supramalleolar osteotomy in the correction of ankle varus.

available; while in the third, the roentgenogram showed a doubtful fusion thirteen months after operation, but clinically, arthrodesis is present three years later. Excessive equinus of 19 and 22 degrees may be a factor in two patients, because of induced strain. In two, the roentgenograms reveal arthritic changes at the talocalcaneal joint in one, and at the cuneonavicular articulation in the other. In the eighth patient, the foot is stiff and in mild varus, with ankylosis of the talonavicular joint following postoperative infection.

In the group of eight individuals who are having considerable pain, failure of fusion is present in one, and probably in another. The fibular malleolus in one case did not unite with the talus, and an arthritic reaction has occurred at this point, as revealed by roentgenograms. Although the ankle is fused, no other cause has been found for the pain, which is referred to the anterolateral aspect of the joint. Refusion of the lateral talomalleolar joint has been advised. One patient has residual varus, following incomplete correction of a marked degree of deformity; and another, who had a triple arthrodesis for arthritis of the talocalcaneal joint, apparently has a non-union of the subtalar articulation. In two patients, subtalar arthritis is probably present. In another, roentgenograms show considerable arthritic reaction in the talocalcaneal and talonavicular articulations; triple arthrodesis has been advised, but has been declined, as the patient considers that she is not having sufficient pain at present to warrant the operation.

The chief causes, therefore, of persistent pain appear to be failure of fusion of an arthrodesed joint, varus, or excessive equinus, and concomitant subtalar or tarsal arthritis.

Limp

The presence or absence of limp has not been recorded in ten of the patients. In the remaining twenty-eight, when walking with shoes, a limp was absent in twenty-four, or 85.7 per cent., and present in four, or 14.3 per cent. In the four, the limp appears to be due to arthritis of the subtalar joint in one; probable lack of fusion of the talocalcaneal joint following triple arthrodesis for arthritis in another; poor shoes and a pantalar arthro-

desis in a third; and probable failure of fusion at the right ankle and subtalar arthritis on the left in the fourth, the one bilateral case. Without shoes, limping is more frequent, especially in those in whom the amount of equinus exceeds 15 degrees.

The use of a heel of correct height for the degree of equinus, and the development of compensatory mobility in the subtalar and tarsal articulations are the chief factors in promoting a normal gait in the presence of a fused ankle. Every effort should be made to secure the position of 10 degrees of equinus, because this amount affords facility of walking with or without shoes.

SUBTALAR AND TARSAL ARTHRITIS

Subtalar or tarsal arthritis was revealed roentgenographically in eight of the patients before operation, and in four others after operation. This constitutes 25 per cent. of the whole group of forty-eight ankles. The talocalcaneal articulation was involved preoperatively in six patients, postoperatively in four; the mediotarsal joint, preoperatively in three patients, postoperatively in one; the cuneonavicular articulation, preoperatively in none, postoperatively in one. The mediotarsal arthritis in one patient was associated with a pseudarthrosis which had resulted from an operation performed a number of years earlier to correct forefoot equinus following the original injury.

The degree of arthritis varied considerably, and ranged from marked articular change to mild thinning of the joint space or slight lipping at the articular margins.

To control this complicating condition, a subtalar or triple arthrodesis was performed in five of the twelve patients, while a talocalcaneal fusion was done in one, and a refusion of the mediotarsal joint in another. Both of these latter procedures were performed at the same time as the ankle fusion. In the remaining five patients, no further surgery has been done, but subtalar arthrodesis has been advised in at least one. Two of the five are having considerable pain; two, mild discomfort at times, and one is free from symptoms. The roentgenograms in this case, made before operation, showed only slight lipping posteriorly at the talocalcaneal joint; no further roentgenograms have been taken since the cast was removed, at which time fusion was demonstrated to be present. Clinically, tarsal mobility is good.

The presence of a concomitant subtalar or tarsal arthritis must always be considered in the examination and study of these cases, as it may be a major factor in the subsequent function of the foot. Usually, it is probably related to the original trauma; but it can develop after operation as it did in four patients of this series.

Arthritis in mild degree should be treated with support and physical therapy; but when it is present to a considerable or marked degree, either subtalar or triple arthrodesis should be done, or the patient should be informed of its presence and of the possible necessity for further surgery later on.

1. Kimberley, A. G.: Malunited Fractures Affecting the Ankle Joint. With Special Reference to Twenty-Two Cases Treated by Arthrodesis. Surg. Gynec. Obstet., LXII, 79, 1936.

DISCUSSION

Dr. H. R. Conn, Akron, Ohio: We are indebted to Dr. Hallock for calling our attention to this tibiotalar fusion which in my opinion is not used as widely as it might be. It is applicable to any lesion that produces a disintegration of the articular elements.

As has been observed, compensatory hypermobility of the mid-tarsal joints very quickly develops in these patients, and as a result they suffer less functional disability than might be anticipated.

About ten years ago I showed nine of these patients with fusions to the Ohio State Medical Society. All had had arthrodesis long enough for the maximum degree of hypermobility to develop, and I was not surprised when members of the audience insisted that no true tibiotalar fusion existed. Of course the roentgenograms were available to prove that solid bony fusion was present between the tibia and the talus.

In the early cases, I attempted joint excision and the implantation of chips, but I have had much better results with a sliding bone graft plus chips.

I would re-emphasize the value of this operation and the surprising lack of disability which results.

Dr. J. Warren White, Greenville, South Carolina: I think we are gradually doing more and more of these operations because they are so very satisfactory. There is one little device that I have used which is really a part of the postoperative dressing. I will show it on the board. It concerns the holding of the parts together. You will remember some years ago Key emphasized the importance of positive pressure in stabilizing knees. Why not use the same principle in the ankle? I put one stainless-steel pin, one-eighth of an inch thick, just above the location of the epiphyseal line and another one through the lower posterior portion of the os calcis so that the vessels will be missed. After applying the dressing, I attach rubber bands between these two pins.

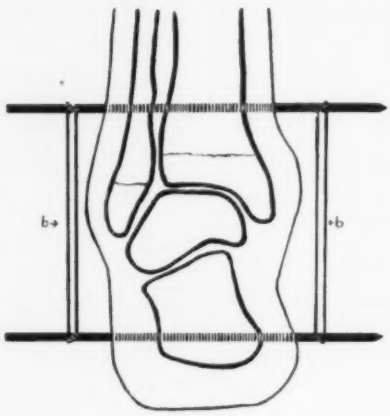

Fig. A

b: Rubber bands.

This makes it unnecessary to extend the cast above the knee. It stabilizes the entire lower leg satisfactorily. I have treated four of these cases in this way. The extreme pressure from the bands is exerted only while the plaster is hardening, which prevents any serious amount of pressure necrosis (Fig. A).

Dr. J. Albert Key, St. Louis, Missouri: Many of these patients have a diastasis with a broad ankle which is undesirable. Also, the objection to the arthrodesis from the front is that, as you take the cartilage off, you narrow the talus and widen the mortise. The more you take off, the worse it fits. I now remove the articular cartilage from the front, and slide a cortical graft from the tibia down through a window or tunnel in the lower end of the tibia into the body of the talus. Then, through a lateral incision, the external malleolus is cut across, driven inward to narrow the mortise, and fixed with a long oblique screw. This gives a neater looking ankle, and it fuses more rapidly.

Dr. W. E. Gallie, Toronto, Ontario, Canada: I want to add a word of support to what Dr. Hallock and Dr. Conn have said. It has been my experience that when the ankle joint has been solidly ankylosed in good position, the patient is relieved of his symptoms and is enabled to walk practically normally.

As they have pointed out, however, there are complications which are serious. The 6 per cent. infection rate and the 20 per cent. failure of arthrodesis are too high to justify complacency. It has seemed to me that the probable explanation of the high infection rate is that the operation is rather prolonged and is severely traumatizing. The failures of arthrodesis are undoubtedly due to imperfection in fitting the raw surfaces of the bones together, or to defective immobilization. To reduce the frequency of these complications, we should try to reduce the extensiveness of the operation, and at the same time make use of more perfect contact of bone surfaces. These requisites may perhaps be found in the method I described some years ago for arthrodesis of the subtalar joint. In this, the arthrodesis was brought about by mortising bone grafts into the talus and os calcis without removing the articular cartilages. In the ankle, the same principle can be employed by removing the articular cartilage from the malleoli and the body of the talus, and by filling the spaces so produced with tightly fitting bone grafts. Additional security may be obtained by sliding a graft down from the anterior aspect of the tibia across the joint line into the neck of the talus.

The number of patients treated in this way has not been great enough to justify any statement as to final results. To date, however, we have operated upon ten patients, and bony union has occurred in all. The operation has the additional advantage that, because the articular cartilage between the tibia and talus has not been removed, no shortening occurs, and there is no additional deformity. In women, this is of particular importance.

Dr. Halford Hallock, New York, N. Y. (closing): I appreciate very much the discussion. We have not used internal fixation at the Orthopaedic Hospital except in a spastic patient. Two vitallium screws were used in one patient. We have felt that internal fixation was not necessary, and we have obtained a high percentage of bony union. The elastic pressure which Dr. White spoke of may be helpful in obtaining compression at the arthrodesed joint, and, if that pressure is not so great as to cause pain and discomfort, it will probably help in initiating bony union. In connection with this, he stated that it would not be necessary to extend the plaster above the knee; but even with the pins as he has shown in his diagram, it seems impossible to prevent some anteroposterior motion at the ankle joint, because of the calf muscles which in part arise above the knee joint. It might be better to use plaster above the knee for a short period of time.

In answer to Dr. Gallie's discussion, I would like to say that his method, with fusion occurring in six months' time, seems to be useful in the ankle without deformity. When deformity is present, however, more would have to be done to obtain a good-looking ankle. Our casts have been taken off in twelve weeks. In 90 per cent. of the cases, fusion has been strong enough in twelve weeks to permit the patient to go without a cast. I think that fact justifies the use of this type of operation to obtain early fusion.

EXPERIMENTAL PRODUCTION OF SCOLIOSIS IN RATS AND MICE

BY JOHN R. SCHWARTZMANN, M.D., AND MERYL MILES, M.S., ST. LOUIS, MISSOURI

From the Department of Anatomy, Washington University School of Medicine, and Shriners' Hospital for Crippled Children, St. Louis

A satisfactory understanding of the mechanism involved in the production of scoliosis in man is yet to be fully reached. One means toward this end has been to create this condition deliberately in laboratory animals by various methods.

Wullstein, in 1902, produced permanent scoliosis in dogs by strapping the animals in a position of lateral deviation for a long period of time; Carey, in 1932, produced scoliosis in rats by transplantation of the animals' tails; Bisgard, in 1935, produced scoliosis in animals by "pleural imbalance", producing massive scarring and fibrosis of the chest by surgical means.

Arnd, in 1903, reported the production of scoliosis in rabbits, with associated rotation and wedging of the vertebral bodies, brought about by unilateral excision of the deep back muscles. Carey mentioned the production of experimental scoliosis in animals by muscle excision. Bisgard reported scoliosis due to muscle imbalance produced by resection of the nerves to the intercostal and sacrospinalis muscles.

Pacher, Haas, and Bisgard and Musselman produced scoliosis in animals by surgical means. They partially destroyed the vertebral epiphyseal plates, thereby causing uneven vertebral growth which resulted in lateral deviation of the spine. Engel and Richer likewise produced disturbances in the growth of vertebral bodies by the implantation of radium into the epiphyseal plate, and by this means produced scoliosis experimentally in animals.

Carey demonstrated in a mechanical model that "dynamic equilibrium of the muscle and bone of the back" must be maintained to keep the normal alignment of the vertebral column. He also presented evidence that combinations of muscle groups in balance and in imbalance bear definite and constant influence on normal and abnormal vertebral alignment, respectively.

In the experiments undertaken in this study, the objective has been threefold:

1. To determine the effect on the alignment of the vertebral column of muscle imbalance, produced by unilateral excision of groups of symmetrical muscles which influence the movements and position of the vertebral column.

2. To determine the effect on the alignment of the vertebral column of bilateral excision of groups of symmetrical muscles which influence the movements and position of the vertebral column.

3. To determine the effect on the alignment of the vertebral column of muscle imbalance, brought about by the operative release of the muscles from their attachments to the vertebrae and the prevention of their reattachment by the interposition of inert material between the muscle mass and the vertebra to which it was attached.

MATERIAL AND METHODS

Both rats and mice were used; thus two groups of experiments were carried out.

In Experiment I, twenty-six healthy, young, growing, male rats were used; they averaged five months of age at the beginning of the experiment. The average weight was 300 grams. These animals were not necessarily litter mates.

In Experiment II, seventeen animals of a Swiss-Colony strain of laboratory mice were used. The average age was three months, and the average weight was twenty-three grams. Both sexes were included, but were segregated in order to keep pregnancy from complicating the experimental results.

The anaesthetic used was veterinary solution nembutal. In Experiment I, an average of 0.21 cubic centimeters of solution per 300-gram rat was injected intraperitoneally. In Experiment II, an average of 0.02 cubic centimeters of solution per 23-gram mouse was injected intraperitoneally. Anaesthesia was complete in five to ten minutes, and lasted for a period of from forty-five to sixty minutes.

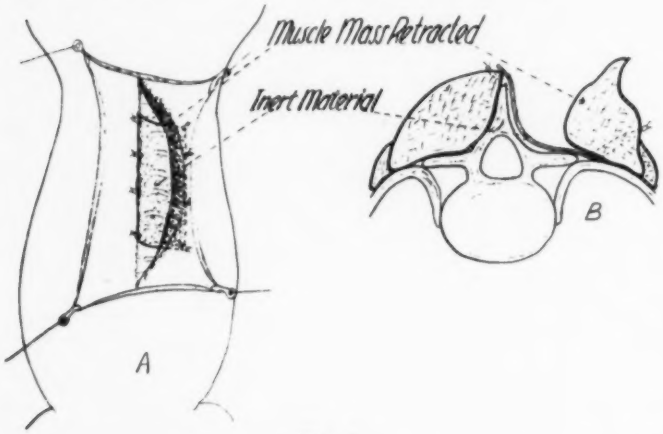

FIG. 1

Showing diagrammatically the method of insertion of inert material after subperiosteal release of muscle mass.

A: Viewed from the operative approach. *B:* Cross section.

The preoperative preparation and postoperative care given to the animals was as follows:

In Experiment I, preoperative preparation consisted in shaving the back from the base of the skull to the mid-lumbar region and for approximately one centimeter on each side of the mid-line. Seventy per cent. alcohol was used as a skin antiseptic; three-minute scrubbing of the hands without the use of surgical gloves, but using sterile instruments, constituted the aseptic precautions. Postoperative care consisted only of allowing the animal free access to water and food, and keeping it in its cage, in a warm room, free from drafts, for nine days.

In Experiment II, preoperative preparation was similar to that given in Experiment I; and the postoperative care was also the same.

The animals used in Experiment II were then exercised regularly in a revolving-drum type of treadmill, as described by Lanier, starting with ten to fifteen minutes daily, and gradually increasing to two hours twice daily, as they were able to tolerate the work. For the most part, the animals had difficulty for about ten days, as they were apparently lame in the extremity on the side operated upon, but after this length of time they seemed able to compensate sufficiently to maintain the gait satisfactorily. Obviously the animals could not be under constant surveillance; often an animal drowned. No wound infections were encountered in any of the animals of either experiment.

The inert substances used were: (a) surgical Penrose rubber drain; (b) commercial cellophane sheets, removed from a given brand of cigarette packages, and sterilized by boiling; and (c) insultoic membrane—chromicized bovine allantois.

EXPERIMENTAL PROCEDURE

Experiment I (Rats)

1. *Unilateral Removal of Superficial and Deep Back Muscles on the Left or Right (Fourteen Rats).* The skin was incised in the mid-line between the levels of the upper border of the scapula and the thirteenth rib. The cutaneus maximus was divided in the mid-line in a similar manner, and was retracted laterally, thus allowing exposure of the superficial back muscles. The spinotrapezius was identified, dissected free from its attachment to the spinous processes and thoracolumbar fascia, dissected to its insertion on the scapula, clamped at its insertion, divided, and removed. The latissimus dorsi was freed with the thoracolumbar fascia throughout its extent of attachment to the spinous processes, was dissected free to within 0.5 of a centimeter of its insertion into the humerus, and was crushed, divided, and removed. This resulted in exposure of the deep back muscles. The entire deep muscle mass (the serratus posterior groups) was separated

from its attachment to the spinous processes, laminae, transverse processes, and ribs between the fourth and thirteenth thoracic vertebrae, inclusive. This muscle group was clamped above and below at the levels of the fourth and thirteenth thoracic vertebrae, respectively, and was removed *en masse* between the clamps. Any residual muscle tissue (such as intrinsic back muscles) was scraped off the laminae, transverse processes, and ribs, and was excised, leaving the bony structures in the operative field exposed subperiosteally. Intercostal musculature was not injured. All clamps were removed, the wound was closed by approximating the cutaneus maximus and skin in their respective layers with interrupted No. 40 black cotton sutures. No dressings were applied. Operative time averaged twenty-five minutes from start to finish. There were no immediate operative deaths. In four of these animals, only the superficial musculature on one side was excised by the procedure described; the deep muscles were not disturbed.

2. *Bilateral Removal of Superficial and Deep Back Muscles (Four Rats).* In the bilateral surgical removal of superficial and deep back muscles, the technique employed on each side was the same as the procedure in the unilateral excision.

3. *Removal of Superficial and Deep Muscles on One Side, and Release of Muscle Attachment to Spinous Processes, Laminae, and Transverse Processes on the Opposite Side, with the Interposition of an Inert Material to Prevent Reattachment (Three Rats).* The technique for removal of muscles on one side has been described. Beyond this point the procedure was altered. On the opposite side, the superficial muscles were released from attachment to the spinous processes; the deep muscle mass was freed from the vertebrae subperiosteally, and was separated by dissection as far laterally as the costal angle. This procedure was carried out through the same extent as that of the muscle excision on the opposite side. After subperiosteal stripping of the deep musculature, a piece of inert material (rubber dam, cellophane, or insultoic membrane) was cut so as to cover exactly the denuded area of the spinous processes, laminae, and rib cage, and this material was sutured in place by interrupted cotton sutures as illustrated. The membrane was sutured across the tips of the spinous processes, and anchored to the interspinous ligaments (Fig. 1). Wounds were closed as already described. In three additional animals, unilateral release of muscle attachment was maintained by interposition of an inert material as described above, but in these animals the opposing muscle group was left undisturbed.

Two animals were used as controls.

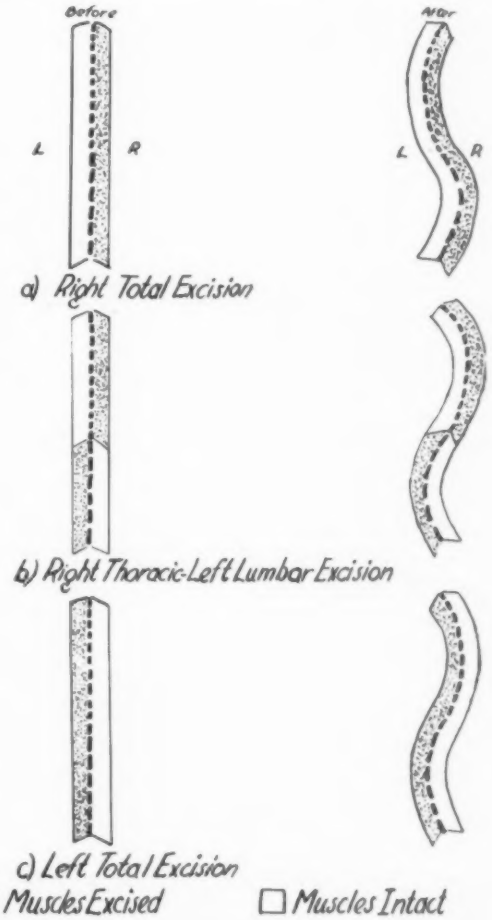

FIG. 2

Diagrammatic representation of the influence of the lumbar curve on the direction of the thoracic curve.

Experiment II (Mice)

1. *Unilateral Excision of Superficial and Deep Back Muscles (Ten Mice).* The procedure of unilateral excision of superficial and deep muscles as described in Experiment I was carried out on mice, except

TABLE I

RESULTS IN EXPERIMENT I

Procedure	Rat No.	Time Observed	Results
(1) Unilateral excision* of superficial and deep back muscles on the left.	1	12 months	Curve was convex to left in mid-thoracic region.
	2	12 months	Curve was convex to left in mid-thoracic region.
	3	8 months	Curve was convex to left in mid-thoracic region.
	4	12 months	Curve was convex to left in mid-thoracic region, and convex to right in lumbar region.
	5	12 months	No curvature was present, but spinous processes were rotated to right in thoracic region.
(1) Unilateral excision* of superficial and deep back muscles on the right.	6	3 weeks	Animal died 3 weeks postoperatively. No curvature was present.
	7	12 months	Curve was convex to right in mid-thoracic region.
	8	12 months	Curve was convex to right in upper thoracic region, and convex to left in lower thoracic and upper lumbar regions.
	9	12 months	Curve was convex to right in mid-thoracic region.
	10	12 months	Curve was convex to right in upper thoracic region, and convex to left in upper lumbar region.
(1) Unilateral excision* of superficial back muscles on the right.	21	1 month	Animal died 1 month postoperatively. No curvature was present.
	22	12 months	Mild curve was convex to left in thoracolumbar region.
(1) Unilateral excision* of superficial back muscles on the left.	23	12 months	No curvature was present.
	24	12 months	Mild curve was convex to left in thoracic and upper lumbar region.
(2) Bilateral excision* of superficial and deep back muscles.	11	8 months	No curvature was present.
	12	12 months	No curvature was present.
	13	8 months	No curvature was present.
	14	12 months	No curvature was present.
(3) Unilateral subperiosteal stripping on left, with insertion of rubber dam (4th through 13th thoracic). No excision of muscle.	16	4 months	Animal died 4 months postoperatively. No curvature was present.
(3) Unilateral subperiosteal stripping on left with insertion of insultoic membrane (4th through 13th thoracic). No excision of muscle.	18	12 months	Curve was convex to right in mid-thoracic region.
(3) Unilateral subperiosteal stripping on left, with insertion of cellophane sheet (4th through 13th thoracic). No excision of muscle.	20	4 months	Animal died 4 months postoperatively. No curvature was present.
(3) Unilateral excision* of deep and superficial muscles on left, and subperiosteal stripping with insertion of cellophane on right (4th through 13th thoracic).	15	3 months	Animal died 3 months postoperatively. No curvature was present.
(3) Unilateral excision* of superficial and deep muscles on left, and subperiosteal stripping with insertion of rubber dam on right (4th through 13th thoracic).	17	12 months	Curve was convex to left in mid-thoracic region.
(3) Unilateral excision* of superficial and deep back muscles on left, and subperiosteal stripping with insertion of insultoic membrane on the right (4th through 13th thoracic).	19	12 months	Curve was convex to left in mid-thoracic region.
Controls,—no operative procedure.	25	12 months	No curvature was present.
	26	12 months	No curvature was present.

* Extent of excision, 4th through 13th thoracic.

TABLE II

RESULTS IN EXPERIMENT II

Procedure	Mouse No.	Time Observed	Results
(1) Total excision* of superficial and deep back muscles in the thoracic and lumbar regions, including the quadratus lumborum, on the right.	5	5 months	Curve was convex to right in upper thoracic region; convex to left in thoracolumbar region; and convex to right in low lumbar region. Pelvis was rotated to left.
	11	4 months	Curve was convex to left in thoracolumbar region, and convex to right in lumbar region. Pelvis was rotated to left.
	13	2 months	Curve was convex to left in thoracolumbar region, and convex to right in lumbar region. Pelvis was rotated to left.
	9	4 months	Curve was convex to left in thoracolumbar region, and convex to right in lumbar region. Pelvis was rotated to right.
	17	2 months	Slight curve was convex to left at thoracolumbar junction.
(1) Total excision* of superficial and deep back muscles in the thoracic and lumbar regions, including the quadratus lumborum, on the left.	16	2.5 months	Curve was convex to left in lumbar region.
	8	6 months	Curve was convex to left in upper thoracic and thoracolumbar regions (excision of lumbar muscles had been incomplete). Pelvis was rotated to right.
	10	4.5 months	Curve was convex to left in upper thoracic region, and convex to right in thoracolumbar region. Pelvis was rotated to right.
	2	5 months	Curve was convex to left in upper thoracic region, convex to right in thoracolumbar region, and convex to left in low lumbar region. Pelvis was rotated to right.
	6	5 months	Curve was convex to right in thoracolumbar region, and convex to left in low lumbar region. Pelvis was rotated to right.
(2) Excision of superficial and deep back muscles in the thoracic region on the right; and in the lumbar region, including the quadratus lumborum, on the left.	4	4 months	Curve was convex to right in thoracic region, and convex to left in lumbar region. Pelvis was rotated to right.
	14	1 month	Curve was convex to right in thoracic region, and convex to left in lumbar region. Pelvis was rotated to right.
Controls	1	4 months	No curvature was present.
	3	4.5 months	No curvature was present.
	7	4.5 months	No curvature was present.
	12	3 months	No curvature was present.
	15	2 months	No curvature was present.

* Extent of excision, 2nd thoracic through 6th lumbar.

that the muscles were excised from the second thoracic through the sixth lumbar, and the quadratus lumborum on the same side was also excised. In some cases, the peritoneal cavity was opened during removal of the quadratus lumborum, but the peritoneum was sutured with the lateral abdominal musculature to the psoas mass, in order to cover the defect produced in the peritoneum and thus prevent evisceration. No immediate postoperative deaths were encountered.

2. *Bilateral but Asymmetrical Excision of Superficial and Deep Muscles (Two Mice).* The superficial and deep muscles of one side of the thoracic spine were excised from the second thoracic through the thirteenth thoracic vertebrae, inclusive; and on the opposite side, the deep and superficial musculature was excised in the lumbar region from the first through the sixth lumbar vertebrae, inclusive, including the quadratus lumborum.

Five mice were used as controls.

DISCUSSION

The results of these experiments in a series of forty-three laboratory animals demon-

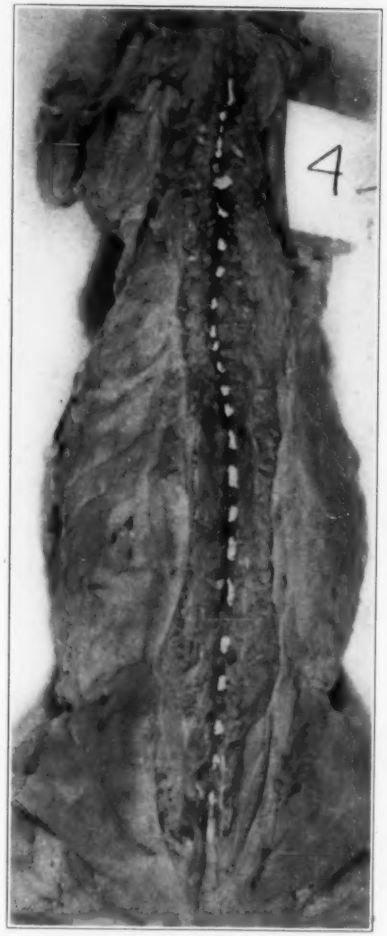

FIG. 3-A

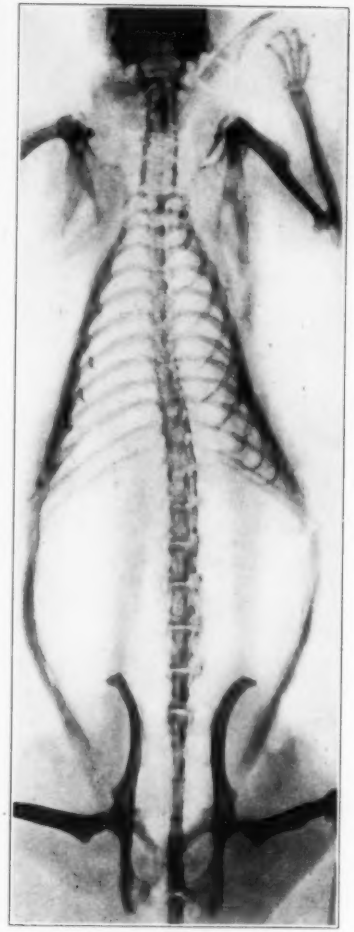

FIG. 3-B

Rat 4. Showing curvature produced by unilateral excision of superficial and deep muscles of the back in the thoracic region, on the left.

FIG. 4-A

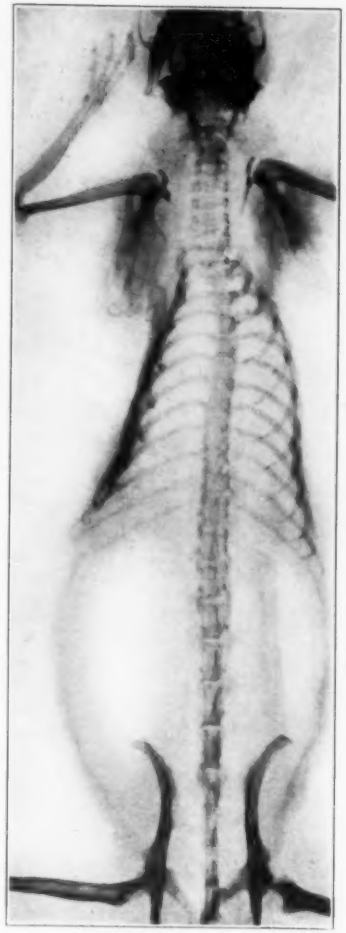

FIG. 4-B

Rat 8. Showing curvature produced by unilateral excision of superficial and deep muscles of the back in the thoracic region, on the right.

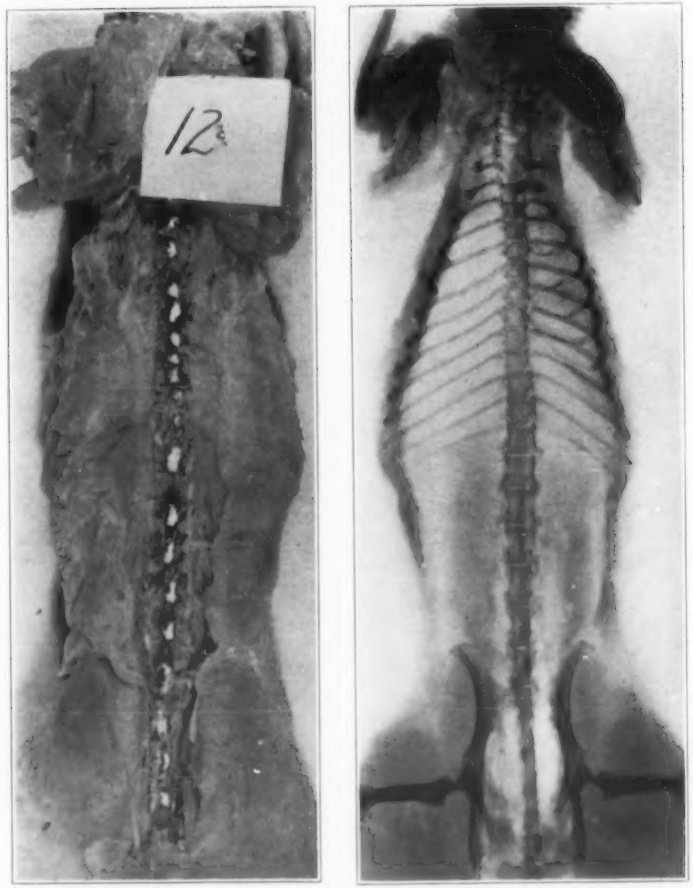

FIG. 5-A FIG. 5-B

Rat 12. Showing result of bilateral excision of superficial and deep muscles of the back in the thoracic region.

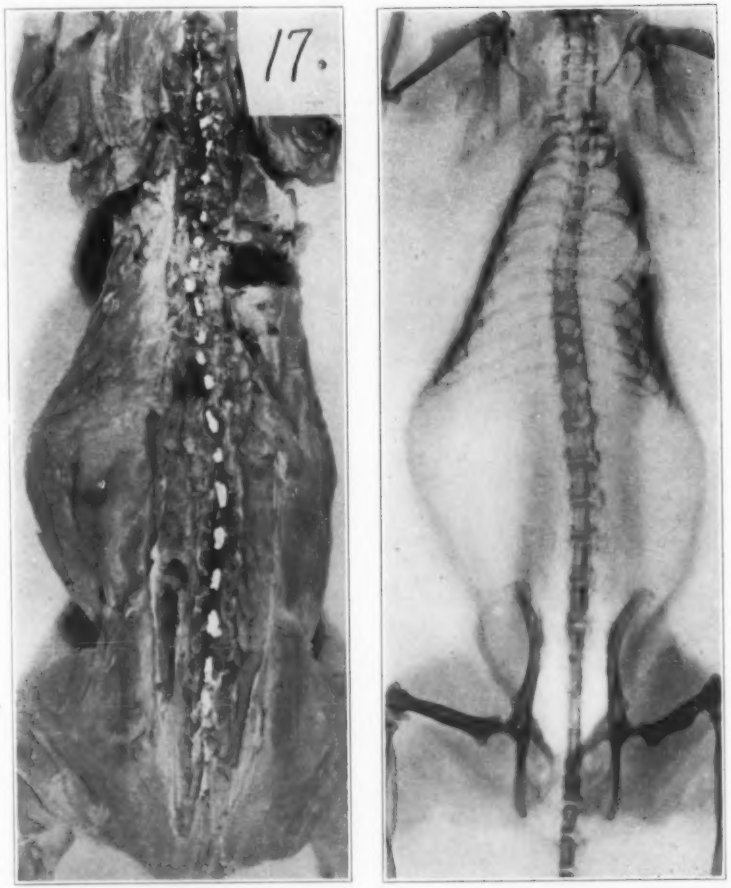

FIG. 6-A FIG. 6-B

Rat 17. Showing curvature produced by excision of superficial and deep muscles of the back in the thoracic region, on the left, and subperiosteal release of muscles of the back with the insertion of rubber dam on the right.

FIG. 7-A

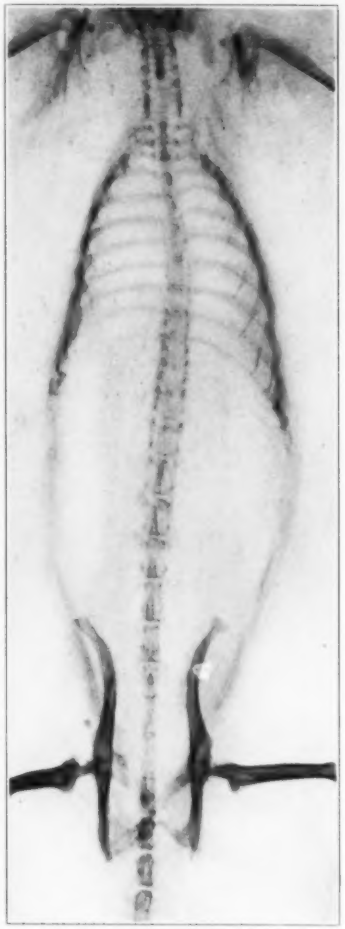

FIG. 7-B

Rat 18. Showing curvature produced by subperiosteal release of superficial and deep muscles of the back in the thoracic region, on the left, and the insertion of insultoic membrane.

FIG. 8-A

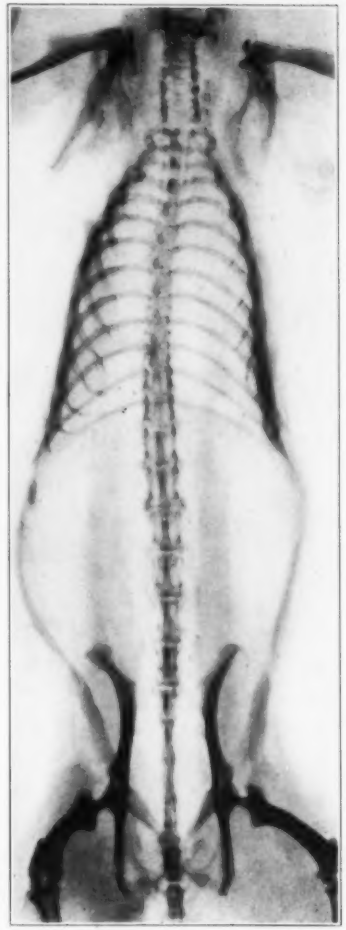

FIG. 8-B

Rat 24. Showing curvature produced by unilateral excision of superficial muscles of the back, on the left.

FIG. 9-A FIG. 9-B

Mouse 5. Showing curvature produced by total excision of superficial and deep muscles of the back, on the right.

FIG. 10-A FIG. 10-B

Mouse 2. Showing curvature produced by total excision of superficial and deep muscles of the back, on the left.

strates readily that scoliosis can be produced in quadrupedal animals, when muscle imbalance is obtained in those muscle groups affecting the alignment of the vertebral column. It is also apparent that a definite time element is necessary for the scoliosis to be produced. In rats, the minimum time for production of a lateral curve by the technique described is somewhere between four and eight months. No curves were found in animals on whom autopsies were performed at or before four months, but expected curves were present in those on whom autopsies were performed at eight months. It was for this reason that the two experiments differed. In an effort to produce results earlier, the mice in Experiment II were worked on a treadmill, since it was felt that in a system of muscle imbalance, regular exercise would increase the power of stronger or unopposed muscles, and, thereby, would cause the scoliosis to appear sooner. This contention is believed to be supported by the results, since curvature appeared as early as one month after operation in the mice. Definite evaluation of the influence of exercise on the time required for the production of curvature in such an experiment, however, calls for a series, comparable except for exercise, in the same type of animal.

In Experiment I, unilateral excision of deep and superficial muscles produced curvatures in a constant direction (Figs. 3-A, 3-B, 4-A, and 4-B), the convexity being toward the weaker or "paralyzed" side, except for Animal 5, which showed no lateral deviation, but rotation of the spinous processes toward the stronger side.

Bilateral excision produced no muscle imbalance and thus produced no curvature (Figs. 5-A and 5-B).

The insertion of inert material to produce selective muscle imbalance offers a most interesting possibility for future investigation. Animals 17, 18, and 19 were the only three of this group which survived

FIG. 11-A FIG. 11-B

Mouse 4. Showing curvature produced by excision of superficial and deep muscles of the back in the right thoracic region and the left lumbar region.

long enough for results to be observed. Both animals in which cellophane was used died within four months; whether or not the cellophane produced death is not known. One of the two animals in which rubber dam was used died at four months, the other (Animal 17) lived for the length of the experiment, and a curvature developed. In this animal (Figs. 6-A and 6-B), tissue section through the area of the rubber insertion (with Weigert stain) showed a marked amount of fibrosis. None appeared in Animals 18 and 19, in which insultoic membrane was used. Release of the attachment of the intrinsic back muscles on one side, with excision on the opposite side, resulted in curves convex to the weak side in Animals 17 and 19, whereas simple release of the attachment of the intrinsic muscle on the left in Animal 18 (Figs. 7-A and 7-B) resulted in a curvature to the right, which would be expected to be the stronger side. This indicates that the intrinsic or short back muscles may alter considerably the influence of the long or "bowstring" muscles on the alignment of the vertebral column.

The use of inert material to bring about selective muscle imbalance offers a means of studying the influence of certain individual muscle groups on the alignment of the vertebral column. In the animals studied, the use of insultoic membrane was found to be the most satisfactory, since microscopic sections through the areas of implantation of inert material showed that no local tissue reaction to the introduction of this substance was encountered, whereas considerable fibrosis and scarring were present around the insertions of cellophane and rubber dam.

No explanation is offered for the curvature being to the left only, in excision of either right or left superficial muscle groups (Figs. 8-A and 8-B).

In Experiment II, excision of the deep and superficial muscle mass throughout the length of the thoracic and lumbar spine produced double or S curves. Constantly the convexity was toward the weak side in the lumbar region, as one would expect. The thoracic curve, however, was convex toward the stronger side. When the direction of the lumbar curve favored it, as in Animal 4, the thoracic curve was convex toward the weak side, as in excision of the right thoracic and left lumbar musculature (Figs. 9-A, 9-B, 10-A, 10-B, 11-A, and 11-B). Comparing this with the results in Experiment I, where it was found that with thoracic-muscle imbalance only, the convexity was toward the weak side, *it is strongly suggested that a lumbar curve will ultimately affect the direction of the thoracic curve.* This statement is presented diagrammatically in Figure 2. An inconsistency in this observation is apparent in Animals 8 and 10, but we believe that incomplete excision of the lumbar-muscle group in Animal 8 may account for the deviation from the expected results. In Animal 10, the period of observation was only four months, the low convexity to the right was in the thoracolumbar region, and it may be suggested that the curve was not fully developed at the time the animal died.

Experiment II also demonstrates a method of studying the progressive stages between beginning and maximum curvature. For example, animals observed for periods of two, four, and five months, following right total excision, showed varying degrees of curvature from mild single-curve scoliosis to severe triple curvatures, with a left convexity in the thoracolumbar region common to all the animals. Animals observed for periods of from two and a half to six months following total excision on the left also showed curvatures varying from single-curve scoliosis to triple curvatures.

Carey, by the medium of an ingenious mechanical system, demonstrated the influence of individual muscle pull on the alignment of the vertebral column. He also demonstrated mechanically that combinations of muscle groups in balance and in imbalance have definite and constant influence on the vertebral alignment.

In this experiment there have been demonstrated, *in vivo*, some of the mechanical imbalances presented by Carey in an inanimate model. Thus scoliosis has been produced by selective muscle imbalance, which simulates the mechanical condition of paralytic scoliosis.

Scoliosis, secondary to poliomyelitis, is dependent upon muscle imbalance, which is

due to asymmetrical paralysis of muscle groups, influencing the normal alignment of the vertebral column. This imbalance may be mild or severe in degree; the location and nature of the curve is dependent upon the type and extent of the imbalance.

Crego and McCarroll have demonstrated that recurrence of deformities in paralytic feet after stabilization may frequently be due to uncorrected muscle imbalance about the foot and ankle; the same principle may well hold true in deformities of the vertebral column, which are due to or influenced by muscle imbalance.

It is believed that the results obtained in this series of animals have been constant enough to warrant certain definite conclusions.

CONCLUSIONS AND SUMMARY

This study of experimentally produced scoliosis may justify the following conclusions:

1. Scoliosis can be produced experimentally in laboratory rats and mice by the selective release of mechanical action of different muscle groups on the vertebral column.

2. A satisfactory degree of control can be maintained to allow the prediction of the type of curve to be produced.

3. Selective muscle imbalance can be produced without muscle excision by the use of inert material to prevent muscle reattachment; this imbalance will produce lateral curvature.

4. Muscle excision and release which did not produce imbalance resulted in no scoliosis in the animals studied.

The authors express appreciation to Mildred Trotter, Ph.D., Department of Anatomy, Washington University School of Medicine, for her cooperation and help in conducting these experiments.

Photographic and roentgenographic material was obtained through the cooperation of Miss A. J. Joslin, R.N., Shriners' Hospital, and Mr. M. W. Rhoades, Washington University.

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CONGENITAL STRICTURE OF THE SPINAL CANAL*

BY PROF. DR. MÜNIR AHMED SARPYENER, ISTANBUL, TURKEY

From The Clinic of Infantile and Orthopaedic Surgery, Istanbul

It is a common phase of pathology that peripheral nerves are very susceptible to pressure, whether this be the sudden pressure of a fractured bone fragment, the gradual pressure of exuberant callus, or the slow envelopment of scar tissue. The nerve gives evidence of the pressure by sensory and motor changes in the part supplied, varying from muscle weakness to complete paralysis, from mild hypaesthesia to complete anaesthesia. Despite this well-known fact, we have thus far largely neglected the study of the congenital causes of pressure against one of the most important parts of the nervous system,—the spinal cord. I refer particularly to the congenital stricture of the spinal canal.

Normally, the spinal canal is narrow in three regions,—above, below, and between the cervical and lumbar enlargements. The spinal cord shows similar variations in its size. Although it is impossible to prove that the enlargement of the canal has any effect on the enlargement of the cord, we do know that in spina bifida occulta there is a stricture of the cord. This causes many clinical manifestations: enuresis of varying grades, pains similar to those in lumbago and sciatica, atrophy of muscles, skin changes similar to vitiligo, and perforating ulcer. I have published papers which show additional effects of

FIG. 1

Case 1. Sevim. The autopsy specimen shows that the spinal cord is divided into two lateral branches, and is reunited after the division. (*Reproduced from Vertebra Bifida.*[2])

FIG. 2

Case 2. Metin. At autopsy, the spinal cord was found to be like that in Case 1,—divided into two branches by a bone and reunited after the division.

* Edited by Leo Mayer, M.D., New York, N. Y.

spina bifida occulta and the associated congenital stricture,—retention of urine caused by paralysis of the urinary bladder, pollakiuria, malacic disease of the legs, retraction of the urinary bladder caused by a cystitis resisting treatment, and ascending inflammation of the urinary tract caused by enuresis. In fact, 56 per cent. of the cases of urinary calculi in Turkey, which were caused by a long continued cystitis, were due to stricture of the spinal canal.

Thus far, there have been no references in the medical literature to congenital stricture not associated with spina bifida occulta. Studies extending over a long period have convinced me, however, that this pathological entity does exist, that it can be demonstrated by suboccipital injections of lipiodol, and that it is responsible for many hitherto unexplained clinical manifestations,—enuresis, spastic or flaccid paralysis, and various deformities. These patients do not suffer pain. It might, therefore, be argued that no pressure is exerted against the cord. My answer is that certain spinal tumors, which grow slowly, may exist for years without causing pain. Thus Sicard and Laplane, in *La Presse Médicale* of January 10, 1925, reported the case of a soldier in whom, in 1916 following a concussion of the brain, a spastic paralysis developed. This was variously diagnosed as hematomyelia, syringomyelia, multiple sclerosis, Pott's disease, and myelitis syphilitica. The patient had no pain. Despite this, Sicard suspected a spinal-cord tumor, because of a lipiodol block following suboccipital injections, and cured him by laminectomy and removal of the tumor.

Just as tumors of the spine may cause spastic or flaccid paralysis, so congenital strictures may produce one or the other form of paralysis. The particular type is due not to the location of the lesion, but to the degree of pressure exerted on the cord.

Thus far, I have been able to differentiate the following forms of congenital stricture of the spinal canal:

1. A narrowing of the canal, forming a ringlike constriction of the cord at one or more levels. This variety is usually found in cases of enuresis, and is readily cured by laminectomy. The relief of symptoms comes within a few hours of the operation.

2. More extensive strictures, involving an entire region of the canal. This type is usually associated with spastic paralysis similar to that seen in Little's disease.

3. A localized stricture, causing compression of the spine and paralysis of certain groups of muscles. This is the type responsible for club-foot.

4. Atypical cases, causing a cleft either in the cord alone or in both cord and dura mater.

Our knowledge of the last group is based on two postmortem examinations.

FIG. 3-A

Case 3. Naci. Roentgenogram of patient with enuresis, showing spina bifida occulta at the fifth lumbar vertebra.

FIG. 3-B

After a suboccipital injection, the lipiodol stayed at the first lumbar vertebra where there was no spina bifida occulta.

CASE 1. Sevim, a child, five months old, was admitted to our Clinic, December 2, 1936. There was a tumor in the

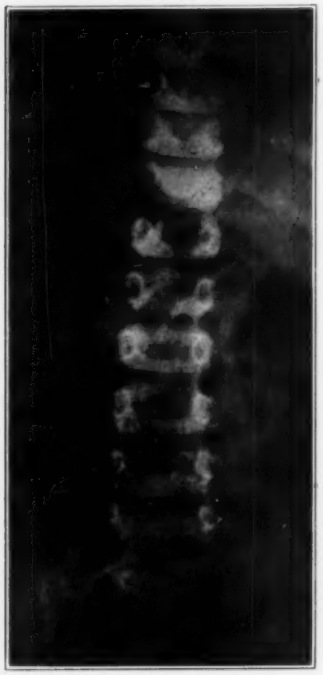

FIG. 4-A

Case 4. Fehmi. Roentgenogram of a patient with enuresis showed spina bifida occulta of the first sacral vertebra.

FIG. 4-B

After suboccipital lipiodol injection, the lipiodol remained at the third lumbar vertebra, where there was no spina bifida occulta.

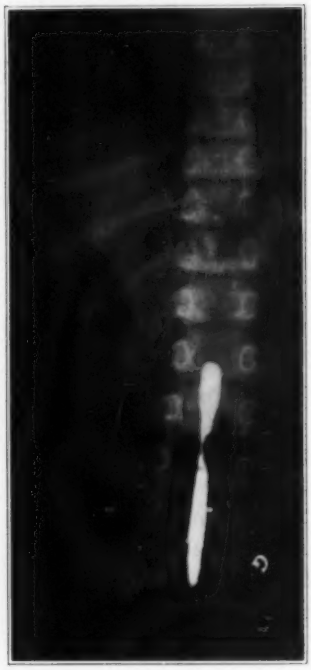

FIG. 4-C

After laminectomy, part of the lipiodol descended to the sacral vertebra.

FIG. 5-A

Case 5. Serafettin. Roentgenogram of a patient with enuresis showed spina bifida occulta.

FIG. 5-B

After suboccipital lipiodol injection, the lipiodol remained at the third lumbar vertebra.

FIG. 6

Case 6. Meliha. This patient had enuresis, but no spina bifida occulta; however, the lipiodol stops at the third lumbar vertebra.

lumbar region as large as an orange, covered with a thin layer of normal skin. Pressure against the tumor caused a bulging at the fontanel. The right leg showed slight paresis, the left foot was claw-shaped, and the big toe was held hyperextended. The right leg was hypaesthetic, the left had normal sensitivity. The roentgenogram of the spine showed failure of fusion of the arches of many vertebrae posteriorly. Twenty-four hours after the resection of the tumor, the child died of shock. At autopsy, an extensive bone formation was found, which divided the spinal cord into two lateral parts (Fig. 1). This bone flattened the posterior portion of the canal to such an extent that the spinal cord bulged out through the hiatus in the posterior arches of the vertebrae.

Case 2. Metin, five years old, born in Instanbul, was admitted because of abnormal gait. There was a tumor the size of a nut in his lumbar region. At operation, extensive bone formation within the canal was found, similar to that in Case 1. This divided the cord into two lateral halves. The dura mater was attached to the bone. The bone was removed in part by rongeurs, but the child died of shock within twenty-four hours. At autopsy, a marked constriction of the canal was found. The compression of the cord was due in part to the abnormal bone formation, and in part to a sleeve of fibrous tissue (Fig. 2).

In the group of cases associated with enuresis, we have noted the lipiodol block usually at the level of the second or third lumbar vertebra (Figs. 3-B, 4-B, 4-C, 5-B, and 6). We know that this represents the region of the spinal cord which controls the bladder. These patients represented a group with severe symptoms not controlled by any conservative measures. At operation it was noted that, before release of the constriction, there was no pulsation of the dura below the level of the lesion; that pulsation returned after laminectomy; and that, as the pressure was released, the dura, together with the epidural fat, bulged through the opening in the region of the laminectomy. These facts, together with the immediate cure of the enuresis following the operation, have convinced us of the presence of a stricture which exerts a significant pressure against

Fig. 7-A

Fig. 7-B

Fig. 7-C

Fig. 7-A: Case 7. Rüstem. Showing patient before laminectomy.

Fig. 7-B: After suboccipital injection, the lipiodol remained at the first sacral vertebra, where there was no spina bifida occulta.

Fig. 7-C: Showing patient after laminectomy.

FIG. 8-A

Case 8. Mustafa D. Photograph before laminectomy.

FIG. 8-B

Two and a half hours after lipiodol injection.

FIG. 8-C

Twenty-four hours after suboccipital lipiodol injection.

FIG. 8-D

Showing condition after laminectomy.

FIG. 8-E

The hygroma was not operated upon, as it was thought that this would disappear in time.

FIG. 9-A

Case 9. Nermin. Photograph taken before laminectomy, showing pes equinovarus.

FIG. 9-B

Twenty-four hours after suboccipital lipiodol injection, the lipiodol remained at the first lumbar vertebra where there was no spina bifida occulta.

FIG. 9-C

After laminectomy, the lipiodol descended to its normal place.

FIG. 9-D

Showing improved condition after laminectomy.

the cord. Although we thought at first that the strictures were always associated with spina bifida occulta, recent cases have demonstrated their presence without demonstrable evidence of spina bifida (Fig. 6).

Our research has demonstrated that many club feet, some of them of the paralytic type, are due to congenital stricture of the canal. Laminectomy has cured these patients. The following illustrative cases are typical.

CASE 7. Rüstem, seven years old, had a right club foot, and had never been able to walk normally. The deformity was said to have existed since birth. There was no history of poliomyelitis. Examination showed a paralytic club foot, due to paralysis of the peroneal muscles and the extensor digitorum longus. This paralysis was confirmed by exact electrical tests. In order to walk, the patient had to abduct the right thigh and support it with his hand (Fig. 7-A). After walking a few steps, he tended to fall. The reflexes were normal. Wassermann reaction was negative. A suboccipital injection of lipiodol showed a narrowing of the lipiodol column at the level of the fifth lumbar vertebra (Fig. 7-B). Following laminectomy in this region, he was able to stand and walk normally, and the club-foot was corrected (Fig. 7-C).

CASE 8. Mustafa, ten years old, had a club foot even more severe, which was complicated by a large hygroma on the dorsolateral aspect of the foot. The deformity was so severe (Fig. 8-A) that manual correction was impossible, and a bone resection was thought to be necessary. The peroneal muscles were paralyzed. The lower half of the leg and the foot were cold and cyanotic. The left foot showed a plano-valgus deformity. There was no history of poliomyelitis. Before any local operation was attempted, a suboccipital injection of lipiodol was given. This showed a peculiar spinal twist of the lipiodol column and a stricture at the level of the fourth lumbar vertebra (Figs. 8-B and 8-C). After laminectomy it was possible to correct the club-foot by simple lengthening of the Achilles tendon by the method of von Baeyer (Fig. 8-E). The hygroma was not removed, because it was thought it would probably disappear spontaneously.

CASE 9. Nermin. In this case, the club-foot was somewhat milder (Fig. 9-A). The lipiodol showed a block at the first lumbar level (Fig. 9-B). The photographs illustrate the result of laminectomy (Figs. 9-C and 9-D).

CASE 10. Zeyneb. This was a most unusual case in an adolescent girl, who, on admission to our Clinic, was barely able to stand alone. Both hips and knees showed marked flexion contractures; both hips were dislocated; the feet were cold; and many of the nails were absent (Figs. 10-A, 10-B, and 10-C). The cause of her contractures was inexplicable until the lipiodol injection showed a stricture at the level of the second, third, and fourth lumbar vertebrae (Figs. 10-D and 10-E). During the laminectomy of the second, third, and fourth lumbar vertebrae, it was noted that the spinal canal was so narrow that it was impossible to introduce a little finger, and there was no pulsation of the dura mater. It seemed to us that there was such a marked failure of development of the cord that the operation would probably prove a failure, and for this reason we did not extend the laminectomy to

FIG. 10-A

Case 10. Zeyneb. Girl in seated position. Note appearance of feet and toes.

FIG. 10-B

Photograph showing feet and toes.

FIG. 10-F

Four months after laminectomy, the patient can stand up and walk slowly without leaning on anything.

FIG. 10-E

Twenty-four hours after suboccipital lipiodol injection, the lipiodol remained at the second, third, and fourth lumbar vertebrae.

FIG. 10-D

Roentgenogram shows no spina bifida occulta.

FIG. 10-C

Before laminectomy, the patient was able to stand up only by leaning on the wall.

FIG. 11-A

Case 11. Dudu. This patient had paraplegia spasmodica (Little's disease). The roentgenogram shows no spina bifida occulta.

FIG. 11-B

Twenty-four hours after suboccipital lipiodol injection, the lipiodol remained at the second lumbar vertebra. The patient could not walk at all. Three months after laminectomy, she was able to walk without leaning on anything.

FIG. 12

Case 12. Mustafa. The patient suffered with enuresis and had a spina bifida with tumor in the sacral region. After laminectomy, the enuresis was not improved. Suboccipital lipiodol injection was made in our Clinic a year later.

FIG. 13

Case 13. Cemal. This was a case of continual enuresis. The patient had a sacrum bifidum and spina bifida with tumor at the first lumbar vertebra. The tumor was extirpated, but the enuresis did not improve.

the thoracic region. To our surprise, however, one month after the operation, the patient had improved enough to walk 120 yards, leaning on a wall, and after four months she could walk without any support (Fig. 10-F).

In ten patients with spastic diplegia, similar to that seen in Little's disease, we found that the lipiodol was blocked, and at laminectomy we were able to prove the narrowing of the spinal canal (Fig. 11-B).

From the study of this series, we are reasonably sure that congenital stricture or narrowing of the canal is responsible for many cases of enuresis, club-foot, and spastic and flaccid paralysis leading to abnormalities of gait and contractures. The narrowing of the bony canal compresses the cord, and, by the law of Delpech, prevents it from normal development. It is also probable that there are congenital strictures of the intervertebral foramina, which cause pressure against the nerve roots. These lesions, unlike those in later life, do not cause pain, since they develop very slowly and tend to inhibit growth of the nerve, whereas the inflammatory constrictions of later life cause sudden pressure against a fully developed nerve, and are, therefore, painful.

The indications for laminectomy are as follows:

1. In uncomplicated cases of enuresis, laminectomy may be postponed until puberty.
2. All patients with enuresis, who have reached adolescence without improvement, require laminectomy.
3. In children of four or five years, who, without assignable cause other than con-

genital stricture of the spinal canal, have never learned to walk, laminectomy should be done without delay, since otherwise irreparable damage to the cord may occur.

4. In cases of abnormal gait, which tend to become worse, and which show congenital stricture of the canal, operation should be done when the patient is five or six years of age.

5. The same rule applies to patients with atrophy or paralysis combined with abnormalities of the lower extremities.

As to the technique of the operation, the laminectomy should include the narrow vertebra and the one just distal to it. In cases of spastic diplegia, five or six vertebrae should be included. The stricture must be completely relieved, and pulsation must return to the dura below the level of the lesion. Great care should be taken not to injure the dura; sponging should be done very gently. If by accident the dura is opened, it should be sutured in such a way as not to cause any constriction. In cases of spina bifida, it is important not only to remove the tumor, so as to prevent its rupture and subsequent infection, but also to release the concomitant stricture, since otherwise symptoms due to agenesis of nerves will probably continue (Figs. 12 and 13).

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SOME REMARKS ON THREE COMMON FRACTURES *

1. Fractures of the Carpal Scaphoid;
2. Fractures of the Head of the Radius;
3. Fractures of the Medial Malleolus.

BY D. M. MEEKISON, M.D., B.SC., F.A.C.S., VANCOUVER, BRITISH COLUMBIA, CANADA

Fractures of the carpal scaphoid, head of the radius, and medial malleolus were encountered very frequently in the Royal Air Force during the author's years of service in that branch of the British Armed Forces. Certain conclusions on some aspects of these will be presented, perhaps dogmatically, together with series of cases of each fracture, composed of the author's patients, accumulated for the most part during one year.

FRACTURE OF THE CARPAL SCAPHOID

In considering this fracture, one is reminded of an apt remark by André Gide, who prefaced an essay with:

"Tout c'est déjà dite; mais comme personne n'écoute, c'est toujours nécessaire à recommencer!" †

How true this is of scaphoid fractures! How much preaching and writing and investigating have been done on this subject; yet we cannot persuade everyone to immobilize this bone as soon as it is fractured. Indeed, we cannot make the members of the medical profession sufficiently scaphoid-conscious to have a roentgenogram taken and to make a diagnosis.

Pathology

To create and maintain conditions optimum for blood supply is the surgeon's chief concern. Immobilization of fresh fractures in hyperextension and full radial deviation so impacts the fragments that nourishment is forever cut off from the underfed proximal fragment. Those who decry open operation through a dorsal approach, because the exposure interferes with the blood supply, will purposely and with intent drill a hole through the tubercle and insert a bone graft for established non-union. Surely the nutrient artery enters the bone at that point.

It is difficult to understand why a fracture occurs in the proximal third, since the bone is so well protected from strain at this level. On the other hand, fractures of the waist are quite logical, since the scaphoid lies virtually half in the proximal row and half in the distal row of the carpus; and thus is the only member of this carpal family subject to certain shearing and rotational strains. This brings up the interesting question of why so many fractures of the carpal scaphoid are encountered in the Services, in contrast to the paucity of Colles's fractures. It would seem that the scaphoid fracture is one of youth, due possibly to the fact that strong forearm muscles resist hyperextension and thus project the leverage more distally.

Diagnosis

The expression "sprained wrist" is all too common. Roentgenograms of such a wrist in at least four projections are essential. If one suspects clinically a fracture of the scaphoid, even though the roentgenograms do not reveal it, the wrist should be immo-

* Read at the Annual Meeting of The American Orthopaedic Association, Hot Springs, Virginia, June 1, 1944.

† "All has already been said; but, as no one has listened, it is always necessary to start over again!"

bilized for about three weeks and the roentgenographic study should be repeated. In eight of this series, no fracture was revealed in the original roentgenogram, but was evident three weeks later. This is a most important point.

Another feature of the roentgenographic interpretation is the possibility of overlooking a subluxation of the semilunar; its relationship to the other carpal bones should, if abnormal, be adjusted.

Treatment

Fractures of the carpal scaphoid should be considered under two headings. The first group, fresh fractures, are not a problem; the second, old fractures, are a problem.

Orthopaedic or traumatic surgeons should not miss a fracture of the scaphoid, and, if given the opportunity, they should obtain good results in fresh fractures by closed methods in 100 per cent. of the cases. By closed methods is meant adequate immobilization in plaster in the position best described by Soto-Hall and Haldeman, for eight weeks or more. Properly applied, the plaster need not be changed in less than eight weeks, and by then union is likely to be present. This refers, of course, to waist fractures and those proximal to this level. Tubercle fractures need hardly be treated at all. In cases treated during the past eighteen months, the author has included the thumb in the cast, with the first metacarpal abducted, and has continued the cast to the proximal interphalangeal joints, as suggested by Soto-Hall and Haldeman. It has been gratifying to see the way the plasters stand up. The scaphoid can be immobilized by a shorter cast, but the cast does become loose and requires changing every three or four weeks.

In the treatment of old fractures (unrecognized or untreated for a month or more) there are four methods to consider.

1. *Immobilization.* An old fracture must be immobilized for from four to six months if necessary, depending upon roentgenographic evidence of union; and union must be complete. This treatment is reserved for fractures which are not too old—that is, one to three months—and in which accurate reduction can be obtained.

2. *Excision.* This applies to the proximal fragment, when it is the smaller of the two and shows evidence of aseptic necrosis. Excision should never be done when the fracture is at the waist. If excision is undertaken, it should be done early, before changes can take place in the articular cartilage of the radius. Aseptic necrosis can be recognized by the end of eight weeks.

3. *Bone Graft.* The simple dorsal approach, using a peg or inlay graft, is the safest. In seventeen of the 115 cases, bone grafts of this type were used and produced good results. This procedure was originally described by Gordon Murray, and, with modification, it offers the opportunity of holding the fracture reduced by means of a Thomas spike *, while the graft is placed. The use of the blind peg graft is unwise. It is time-consuming and not always accurate. It is difficult to place a straight graft in a curved bone, and the author has seen the radius, the semilunar, and even the ulna, impaled by this procedure. Furthermore, anatomically, it must destroy the nutrient artery.

4. *Arthrodesis of the Wrist.* In old scaphoid fractures with arthritic changes in the adjacent carpal articulations, any surgical procedure short of arthrodesis of the wrist is futile. Arthrodesis offers freedom from pain and a strong wrist, if adequately done. It is true, dorsiflexion and volar flexion are lost, but supination and pronation, which are far more important, are preserved. The procedure of choice is the bail graft, described by Brittain. It really works beautifully, but Brittain has neglected to mention, in the description of his operation, the necessity of eliminating all available articular cartilage.

* This instrument will be found most useful in many open operations on bones and joints. It would seem to have been devised by a surgeon of St. Thomas's Hospital in London in the years gone by, and named by him after his Hospital. It is something like a raspatory, about eight inches in length, with a slightly curved and rounded blunt tip and a fenestrated handle. One may poke about with it in all manner of places without doing damage.

Analysis of Series

Of the 115 cases in this series, seventy-seven were treated from the beginning, and could be considered fresh fractures. It is interesting to note that of these, sixty gave excellent results by adequate immobilization; the remainder of the group were still under treatment when the author left the station. When first seen, thirty-eight had been without treatment for a month or longer (in some cases, even years after the original injury). In this group the following complications were found: arthritic changes in fourteen, cystic degeneration in twenty-two, and aseptic necrosis of the proximal fragment in two. Of the 115 cases, only four resulted from aircraft crashes. Ninety-three were fractures at the waist, fifteen were distal to the waist including the tubercle, and seven were in the proximal third of the bone.

FRACTURES OF THE HEAD OF THE RADIUS

Pathology

The radiohumeral articulation is a precision joint; the slightest eccentricity, caused by tilting of the head, limits its function. Nor is there any room between the head of the radius and the capitellum for any extraneous material,—such as that produced by a fracture through the head. It would seem logical, then, that a damaged or tilted head is a detriment to the function of the joint, and should be removed. This was our very definite conclusion in this series, with the reservation that, if the fracture is not fresh, a good result—such as one obtains in excision of the head following a fresh fracture—is not to be anticipated.

The patients who were not operated upon came early in the series, and were considered to be borderline cases at that time. Their convalescence was so tedious that we wished, in the light of our later knowledge, that we had done an early excision of the head. The incidence of visible damage of the capitellum, as seen at operation and not visible roentgenographically, was striking. On reflection, it is a logical result of the injury. Either the head of the radius strikes the capitellum or the capitellum strikes the head of the radius. If there is sufficient force to damage the head of the radius, so that the damage can be seen in the roentgenogram, then there must be some damage to the capitellum. When both are damaged, dysfunction must result.

Why fractures of the head of the radius are so extraordinarily common in the Service is not clear. Two factors, at least, contributed in no small way to our series,—falls from bicycles and falls during the blackout. Falls in the blackout were extremely common, and not infrequently resulted in fractures of the scaphoid or of the head of the radius. Bicycles were in exceedingly common use. Oddly enough, the bicyclist not infrequently falls with the elbow underneath him, and not on the outstretched hand; it is in these accidents, almost invariably, that the most severe damage is done to the articular surface of the capitellum.

Treatment

The fresh fracture in patients beyond the growth period is really not a problem. Excision within a week or so of injury is advocated; and the excellent results obtained justify the treatment. The old fracture, with organized transudate within the capsule, with limited movement, and with pain at the extremes of the arc of movement, is a real problem. One may easily correct the mechanical disadvantage of an irregular or eccentric head, but, so far as I am aware, there is no solution for the problem presented by changes that have taken place in the capsule.

Operation. With the elbow flexed to about 90 degrees and the forearm pronated, the shortest possible incision, 3 to 3.5 centimeters, is made, axial in direction and lateral to the head of the radius. It is so placed that the joint level is approximately at the junction of

the upper and middle thirds. The extensor origins are separated in the line of the fibers by blunt separation, and the joint capsule is exposed and incised. Just sufficient exposure is obtained to bring the head into view and to allow the insertion of a Thomas spike on either side, just distal to it. The neck is sectioned at the level of the superior border or the orbicular ligament; the head can then be easily withdrawn. The stump of the radius is inspected while the forearm is supinated and pronated, and all irregularities are removed. Tiny fragments are carefully searched for, and, if present, are removed. The articular surface of the capitellum is inspected. The capsule is folded in between the capitellum and the stump by means of a catgut suture, coapting the anterior and posterior portions of this structure to act as a partial covering for the stump, and the wound is closed. As a rule, the skin requires only four interrupted sutures. The operation is done, of course, under a tourniquet.

Exercise. Active movement is commenced as soon as possible following operation, virtually as soon as the patient is awake. Each patient is carefully trained in all the essential movements. It is wise to demonstrate to the patient before operation and on the uninjured arm, just what is expected of him in the way of movement after operation. Supination, pronation, extension, and flexion, even at the expense of some pain, are carried out as thoroughly as possible. Passive movement by the surgeon is frequently indicated. It is important, too, that the shoulder, wrist, and fingers be not neglected. Slings are not allowed. A good result may be anticipated in a fresh fracture in from three to six weeks.

Analysis of Series

This series comprises 110 cases of fracture of the head of the radius occurring over a period of two and a half years, and collected by Squadron Leader A. E. Burton, R.A.F.V.R., and the author. It includes all varieties from comminuted fractures to simple fissure fractures. Among them were only six fractures of the neck, without involvement of the head, and with minor tilting. Of the 110 patients, seventy-eight were operated upon; and, as time passed, and end results accumulated, the conclusion was reached that all fractures of the head or neck of the radius require surgical interference. Of the seventy-eight patients operated upon, fifty-seven showed definite evidence of injury to the articular cartilage of the capitellum, ranging from fine crenulation to complete avulsion. Of the thirty-two patients not operated upon, only three regained a complete range of movement; and while twenty-four had no pain, eight continued to complain of pain at the extremes of the arc of movement. The average limitation of extension in those not operated upon was 15 degrees. All seventy-eight patients who were operated upon ultimately had no pain. Cases in which late operations were performed were much more resistant, the average limitation of extension being 5 degrees. In the 110 cases, there was one complication,—damage to the dorsal interosseous nerve, caused no doubt by contusion from traction at the time of the operation. When the patient was last seen, some six months after operation, there was no sign of recovery in the extensor pollicis longus.

FRACTURES OF THE MEDIAL MALLEOLUS

Pathology

In every patient with displacement, operated upon by the author (fifty-three cases), soft parts were found interposed between the malleolar fragment and the shaft. In nearly a quarter of the cases, a small loose fragment of bone and cartilage was found lying within the joint at the posterior end of the fracture line. This was occasionally seen in the roentgenogram.

Treatment

The treatment of simple fracture of the medial malleolus with displacement is, in the author's opinion, open reduction and internal fixation (vitallium screw), if adequate facilities are available and the surgeon's operative technique is above reproach.

Operation. An incision is made over the medial malleolus, sufficiently long to permit visualization of the anterior and posterior margins of the tibia, and, second, to allow sufficient clearance below the malleolus for the insertion of the screw. It should be pointed out that this incision is made directly over the center of the malleolus, and at no time has the author had any complaints about the operative cicatrix over this prominence. It may be that the invariable use of interrupted vertical mattress sutures of some form of nylon in the skin contributes to the usual hairline, painless scar. The operation is always done under tourniquet, and skin towels are always used. The fracture line is thoroughly cleared, and the fragment is replaced in accurate position. The criteria of this accuracy are the fitting of the "pattern" of the fracture line and the congruity of the anterior and posterior borders of the tibia. A sharp hook holds the malleolus in position, while a vitallium screw is inserted across the fracture line and into a suitable drill hole. The head of the screw is well buried, and there is no necessity to remove it at a later date. A below-the-knee padded cast is applied with the foot in mid-position, for ten to fourteen days, and then a non-padded plaster is substituted. Freedom of movement of the toes is essential in these plasters. Indeed the only indication for a toe platform in any cast applied to the ankle or foot is when the toes are paralyzed. A felt or rubber heel is incorporated in the second plaster. The use of walking irons is discouraged. Union should be solid in eight to ten weeks, and when the final plaster is removed, a viscopaste bandage is applied for one or two weeks to control swelling.

Analysis of Series

Twenty-three fractures of the medial malleolus, treated by open reduction and internal fixation (vitallium screw), have already been reported.[2] The present series of fifty-three is made up of the author's patients treated by the same method before and since the year 1941. An analysis of the number of abduction fractures in relation to the adduction type is of no consequence, except to state that the former greatly outnumber the latter. In any event, the operative treatment is the same.

In this series of fifty-three cases treated by operation, there were three poor results. One of these followed infection, evidently incurred from an ill-advised operation in the presence of an incompletely healed skin abrasion. Another was classified as a poor result because of the presence of rheumatoid arthritis. In the third case, the patient was placed in a lower Service category on the completion of the treatment, because of painful weak feet, although the anatomical result of the fracture was virtually perfect. The fifty-three patients were treated over a period of two years, and the results in fifty were excellent, all of them returning to full duty.

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DISCUSSION

Colonel R. I. Harris, Toronto, Ontario, Canada: Among the interesting additions to our knowledge in the field of orthopaedic surgery, which have come from this War, is that concerning fractures of the carpal scaphoid. It must be the experience of your Army, as it is of ours, that the incidence of this fracture is enormously greater than anyone had any knowledge of before. Just why this is so is not clear, unless it be that we have previously overlooked fractures of the carpal scaphoid. Certainly the combination of thousands of young men engaged in strenuous training or in battle and an adequate medical service to which injuries are immediately referred and cared for has demonstrated that fractures of the carpal scaphoid are surprisingly

common. This is one of the most important items in Dr. Meekison's paper. His statements are confirmed by the experience of the Canadian Army. I know from my experience and from conversation with Lieutenant Colonel Shands that fracture of the carpal scaphoid in men undergoing training is a common experience.

The next item of importance is that the fracture is easy to overlook. Often the injury is diagnosed as a sprained wrist and it is not until considerably later that the fracture is demonstrated by roentgenogram. I have come to believe that the lesion of sprained wrist is very uncommon. Far more frequently what is called "sprained wrist" is a fracture of the carpal scaphoid. It is a sound rule that patients who seem to have a sprained wrist should have a roentgenographic examination to determine whether or not they have a fracture of the carpal scaphoid.

When we state that fractures of the carpal scaphoid are of common occurrence and that they can be recognized on the roentgenogram, it should be clearly stated also that sometimes the initial roentgenogram fails to reveal the fracture. If symptoms persist, following an injury to the wrist in which the initial roentgenogram was negative, another roentgenogram should be taken in ten days to three weeks. Often, the later roentgenogram will reveal the line of fracture which failed to show in the earlier roentgenogram.

The treatment which Dr. Meekison has outlined (early and adequate fixation carried out for a reasonable length of time) is simple and satisfactory; this will result in union in virtually every case, unless there has been considerable displacement of the fragments.

Recently Colonel MacFarlane, who, you will remember, addressed this Association three years ago, has published the results of 300 cases occurring in the Canadian Army in England. One of his important conclusions is that early and adequate fixation invariably resulted in fusion. My belief is that the knowledge of the frequent occurrence of fracture of the carpal scaphoid in young males and the necessity of early recognition and adequate early treatment by prolonged and proper fixation will eliminate the problem in which we originally were so much interested,—namely, the treatment of ununited fractures of the carpal scaphoid. That, as Dr. Meekison said, is a difficult problem, but it can be eliminated as a problem by early recognition of fresh cases and their adequate treatment.

Major Joseph E. Milgram, Clinton, Iowa: I would like to confine my remarks to the difficult group of cases—non-union of the carpal scaphoid—and suggest a new procedure, which by this time, possibly, is being performed by a number of us, all unknown to one another.

I have difficulty in fixing properly the small proximal fragment with a cortical avascular osseous graft. Consequently, in 1936, I commenced to denude the dorsal aspect of both fragments, hollowing them, particularly the proximal one, and packing the continuous cavity so created with cancellous bone. Originally, I removed the packing bone with a hollow punch from the greater trochanter of the femur, using a stab wound for the purpose. More recently, the bone has been obtained through a hinged trap door beneath the crest of the ilium. After hollowing the fragments with drills of increasing diameters, curettes, and slow-speed dental burrs, and packing them with bone, I have preferably not closed the avascular capsule over the site of implantation, but have simply closed the subcutaneous tissue. The gripping position compresses the cancellous plug. I have had the opportunity of doing only ten cases, nine of which have united with a bony bridge across the gap. In one, aseptic necrosis of the proximal fragment has persisted. So much for this small group.

Incidentally, I have not been convinced that every non-union of the carpal scaphoid merits intervention. Sometimes, I think we are influenced too much by roentgenographic findings. I have seen a symptomatic non-union of the carpal scaphoid persist without arthritis; and, in another case of non-union, I have observed apparent union occur years later, spontaneously. Furthermore, at operation for old non-union, the articular cartilage has often shown little or no evidence indicative of the presumably inevitable arthritic changes prophesied. Often, there is little correspondence between roentgenographic appearance and function.

Dr. D. M. Meekison, Vancouver, British Columbia, Canada (closing): Dr. Milgram, I do not think bone-grafting for non-union is always necessary. I have seen more than one patient with a completely ununited scaphoid, who has completely normal function. One was my own radiographer in England. He has full use, although he had complete non-union.

INTERNAL DERANGEMENTS AND FRACTURES INVOLVING THE KNEE

Results of One Hundred and Fifty Consecutive Arthrotomies Performed at a Station Hospital

BY MAJOR WILLIAM F. STANEK

Medical Corps, Army of the United States

Injuries to the knee, both recent and old, constitute one of the major problems of orthopaedic surgery in the Army. As a result, there is much discussion of the advisability of performing surgery for internal derangements, especially those which have existed prior to the soldier's entry into the Service. Some surgeons assert that few soldiers so operated upon return to full duty.

Knee surgery can be performed by competent surgeons under the conditions found in a well-run operating room, without undue danger to the patient. Under no other circumstance is any elective surgery justifiable. In the cases reported, there was no instance of infection, and no patient was subjectively worse following operation. Full motion has not been regained in all cases of fracture, and, in one case, in which a hemangioma was removed, there was marked loss of flexion. The routine use of a narrow Esmarch tourniquet resulted in two transient paralyses.

The criticism that these men do not return to duty is difficult to answer. The patients whose cases are reported have been followed closely during their stay at Camp Crowder. Further follow-up has been difficult, but has been successful in many instances. Where it is probable that the man has been discharged from the Service, because of change in regulations, this fact has been noted in the tables. The last patient in the series was operated upon four months prior to the writing of this paper, and the longest detailed follow-up has been twenty-one months. The "follow-up" given in footnotes to each table is the average length of time in all cases between operation and the last recorded hospital visit or discharge from Service. The review showed that when both patient and surgeon were satisfied with the result, the check-up visits were few. When the result was unsatisfactory to the medical officers, especially when the man also was dissatisfied, overseas clearance could not be given, suitable duty assignments were difficult to find, and the follow-up rose from 3.2 months in Class I to 12.5 months in Class IV.

Surgery in the Army has been likened many times to civilian compensation work. This does not give a true picture of the prevailing conditions. The discrepancy between the results obtained in private practice and in insurance practice is explained by the desire of the patients in the latter group to obtain money without working for it, and failure to recover is thought to be due to their hope of receiving a cash settlement. Continuance of pay while in the hospital may prolong a soldier's convalescence, but I do not believe that many soldiers, while under treatment, give thought to later claims against the Government. They may, however, desire discharge from the Army, and frequently fall back on their operation as a means of obtaining discharge or of avoiding distasteful duty.

To properly appreciate the final results in these cases, it must be realized that they have been reached under changing regulations and directives. It can readily be seen that fluctuating physical standards operate to permit the discharge of certain of the men on whom knee surgery has been performed, and their loss from the Service should not be charged to the surgery done. Those patients marked on the tables "discharged as unskilled" had all been previously classified for limited duty only.

One hundred and fifty arthrotomies have been reviewed. These cases have been divided into six classes, in order that they might be more readily evaluated. The first seventy-five cases were originally tabulated in January of 1943, and included the patients

operated upon between April and December 1942 (Group 1). On the basis of the results obtained, certain changes were made in the type of case considered for operation. The second series of patients were operated upon between January and October 1943 (Group 2). By showing the first and second seventy-five cases separately, it is hoped to emphasize this change. The more interesting and unusual cases have been briefly abstracted.

A few technical considerations should be emphasized. In every case, exploration of the anterior chamber of the knee has been continued until definite pathological changes have been located, or a thorough examination has been completed. Negative, as well as positive findings, have been recorded on the operative sheets, a fact of considerable importance in the later evaluation of several of the cases. Where a meniscus has been removed, as much of it has been taken out as could be obtained through an anterior incision. When it has been thought that the remaining portion might cause later difficulty, a Henderson incision has been used to obtain the remainder of the meniscus. In simple cases of injury to the meniscus, sheet wadding and muslin dressings have been applied, quadriceps-

TABLE I

CLASS I. MAJOR CHANGES IN SOFT TISSUE

Location of Injury	Case No.	No. of Cases	Disposition
Group 1[1] (Cases 1 through 75)			
Injury to the meniscus		23	Full duty
	25	1	Discharged as psychoneurotic
	38	1	Disability discharge
	40	1	Overage discharge
	63	1	Limited duty
Injury to the meniscus and hypertrophy of the fat pad		3	Full duty
Injury to the meniscus and rupture of a cruciate or collateral ligament		6[2]	Full duty
	29	1	Discharged as unskilled
	50	1	Limited duty
Injury to the meniscus and mild arthritic change		5	Full duty
	37	1	Discharged as unskilled
	23	1	Discharged as unskilled
Injury to the ligaments or fat pad, without damage to the meniscus	27	1[3]	Limited duty
	47	1[4]	Full duty
Group 2[5] (Cases 76 through 150)			
Injury to the meniscus		39[6]	Full duty
	135	1	Discharged as psychoneurotic
Injury to the meniscus and hypertrophy of the fat pad		11[7]	Full duty
	112	1	Disability discharge
Injury to the meniscus and rupture of a cruciate or collateral ligament		5[8]	Full duty
Injury to the ligaments or fat pad, without damage to the meniscus	132	1[4]	Duty[9]

[1] The postoperative follow-up of the patients returned to duty was 3.6 months; the postoperative follow-up of those who were on limited duty or were discharged was 7.1 months.

[2] These cases include one case of tear of the posterior cruciate ligament, one incomplete and three complete ruptures of the anterior cruciate ligament, and one of moderately relaxed tibial collateral ligament.

[3] In this case, there was a tear of the anterior cruciate ligament only.

[4] In this case, there was hypertrophy of the fat pad only.

[5] The postoperative follow-up was 3.2 months.

[6] In one case, calcification was present in the region of the tibial collateral ligament.

[7] The fat pad was removed in five cases.

[8] These cases include one case of relaxed fibular collateral ligament, one case of relaxed tibial collateral ligament, and three cases of complete rupture of the anterior cruciate ligament.

[9] The soldier, although not reclassified, is known to be in a job not requiring maximum use of the knee.

setting exercises have been started on the first postoperative day, and the man has been allowed up without crutches as soon as he could raise his leg unassisted from the bed. This has frequently been on the second or third postoperative day. No attempt has been made to repair torn cruciate ligaments.

A few typical cases from Group 1, Class I, follow:

CASE 25. The patient, aged twenty-five years, entered the hospital with an acutely swollen knee. He gave no history of injury prior to entry into the Service. Flexion was blocked, and, on operation, a tear in the posterior quadrant of the medial meniscus was disclosed. He regained full motion, and had only 0.6 of a centimeter (one-quarter of an inch) of atrophy of the thigh. In spite of the original history given, he later asked the surgeon to sign papers which would support a claim that he had been injured at his last place of civilian employment. He refused to do duty, and was referred to the psychiatrist to determine whether he was psychoneurotic or a malingerer. He was discharged under the former diagnosis.

CASE 38. The patient, aged thirty-six years, was injured in the Army. The lateral meniscus, which was torn in the posterior quadrant, was removed. An operative note said, "slight fraying of the articular surfaces". Full motion was obtained; there was no swelling, but there was 1.25 centimeters (one-half of an inch) of atrophy. Subsequently he continually complained, and the Disposition Board granted a disability discharge, because of the operative note, making a diagnosis of early arthritis. (From the surgeon's standpoint, this patient had a good result.)

CASE 63. The patient, aged thirty years, had a definite history of knee injury, and a bucket-handle tear of the medial meniscus was found on operation. Six months after operation, there was no swelling or limitation of motion in the knee, and no atrophy. He had many complaints of pain in both knees, and was given a limited-service classification, as a means of getting him into work he liked better. A subsequent change in regulations made this man available for full duty.

CASE 50. The patient, aged twenty-four years, injured his knee in 1940, while in Service. Both menisci and the anterior cruciate ligament were torn. There was mild arthritic change. He was of value as an instructor, and is of such character that he will carry out his duties in spite of disability. His condition was improved by operation. Limited service was recommended to permit his continuing as an instructor.

The lessons taught by a review of the first group of cases are rather striking. Of forty-seven patients in Class I, six were discharged, while three more, reclassified to limited duty, might have been discharged, if the commanding officers had desired, on non-medical grounds (as unskilled or unable to do a full day's work). It was evident that men having meniscus injury only *do* return to full duty. When the man is anxious to continue as a soldier, there is no difficulty. When he is inclined to shirk, he can be kept at duty as any other individual with no objective findings but many complaints, provided exploration of the knee has been thorough, so that the surgeon is certain no pathological changes have been overlooked.

Where more than injury to the meniscus is found, the difficulty in keeping a man at duty increases. Those with tears of the cruciate ligaments can be returned to duty; but where damage to the collateral ligaments or mild arthritic change is diagnosed preoperatively, operation is warranted only if the man is of military value and has a marked desire to be a soldier. Otherwise, in spite of operative improvement, he will probably be eligible for a discharge at some time. If a man with a knee of this type continues to complain, the surgeon cannot in honesty force him to duty.

In the second group of cases in Class I, fifty-six out of fifty-eight patients returned to duty. Two cases are of interest.

CASE 93. The patient, aged twenty-four years, had been injured while playing football. At a previous operation the medial meniscus had supposedly been removed. He complained of pain and "popping" in the knee. He had drawer-forward sign, a mildly relaxed tibial collateral ligament, and a palpable mass in the posteromedial part of the knee, which was thought to be the back half of the previously partially removed meniscus. At operation, an entire meniscus (not believed to be regenerated), showing a tear, was removed, and the tibial collateral ligament was plicated. Because of complaints of pain, he was given limited duty. Later he was seen by three officers at a swimming pool. For an hour and a half he did fancy dives, acted as understander for another man to dive from his shoulders, and finally did tricks in the trapeze rings, hanging from heels and knees. Seeing one of the officers at the end of the performance, he admitted the knee was fit for full duty, and he has not returned since.

TABLE II

CLASS II. MAJOR PATHOLOGICAL CHANGES IN BONE OR ARTICULAR CARTILAGE

Group 1 [1]

Condition	Case No.	Associated Pathology					Disposition	Comment
		Loose Bodies	Torn Meniscus	Arthritis	Tear of Cruciate Ligament	Osteochondritis		
Osteochondritis dissecans	18	1		Yes			Full duty	A sergeant with a keen desire to do duty.
	28	2	Yes				Full duty	
	56	1					Duty [4]	
	60	3					Limited duty	One body left in posterior compartment.
Erosion of under side of the patella (chondromalacia)	24						Discharged as unskilled	
	36	4	Yes				Duty [4]	Patella not smoothed.
	44	4					Duty [4]	Patella smoothed.
	42						Full duty	Only a slight roughening of patella.
	64		Yes				Disability discharge	Not improved by operation; patella not smoothed.
	66		Yes				Full duty	Patella smoothed.
	67	6					Duty [4]	One loose body missed; no attempt was made to remove one in popliteal space.
	75		Yes				Full duty	Only slight roughening of patella.
Loose body (removed without thorough exploration)	34						Full duty	
	65						Full duty	
Osteochondroma protruding into the knee	26		Yes				Duty [4]	

Group 2 [2]

Osteochondritis dissecans	86	1					Duty [3]	Loose body removed; no complaint about knee. Unofficial information indicates he received overage discharge at another camp.
	94	1					Full duty	Loose body removed.
	96						Limited duty	Area of recent destruction.
	128	1					Full duty	Patient says "knee perfect".
	145	1					Full duty	
Erosion of under side of the patella (chondromalacia)	82	1	Yes		Yes		Limited duty	Patella smoothed and meniscus removed.
	95	1	Yes		Yes	Yes	Duty [4]	A sergeant of extreme value to his company.
	125						Duty [3]	
Osteochondroma protruding into the knee	121						Full duty	

[1] Postoperative follow-up of the patients returned to duty was 4.3 months; the postoperative follow-up of those who were on limited duty or were discharged was 8.0 months.

[2] Postoperative follow-up was 5.2 months.

[3] The patient has probably been discharged, but no record is available.

[4] The soldier, although not reclassified, is known to be in a job not requiring maximum use of the knee.

Case 112. The patient, aged twenty-one years, complained chiefly that his knee locked and popped. He gave no history of difficulty prior to entering the Army. There were no physical findings except 0.9 of a centimeter (three-eighths of an inch) of atrophy of the thigh. A medial meniscus, with a loose anterior end, and a hypertrophied fat pad showing areas of calcification were removed. Postoperatively, a popliteal cyst appeared. He continued to complain of the cyst and also of cardiac pain. Because of his general attitude, further operation was believed inadvisable. He was transferred to a general hospital, and received a disability discharge because of the popliteal cyst.

One factor in the results is not apparent. During the period that this second group was under treatment, a Reconditioning School was set up. The patients with knee injuries were subjected to intensive physiotherapy, designed primarily to actively build up the quadriceps. During the course, military drill was stressed, and, in the final two weeks, the men went over a difficult obstacle course. During their last week, they marched a minimum of fifty miles. The man did not return to his unit until six or eight weeks after operation. Unless a soldier could produce objective findings, he had difficulty in convincing the surgeon he could not do duty, if he had completed this course.

Review of the cases in Class II is of especial interest (Table II).

Case 64. The patient, aged twenty-one years, gave a history of pain and swelling of the knee, which developed after he had entered the Army. Operation revealed hypertrophy of the fat pad, tear of the medial meniscus, and marked chondromalacia of the patella. The patella was not smoothed. He regained full motion, but later complained of pain in both knees. He felt he was not made worse by the operation, but was not improved. After adequate trial at duty, in which he cooperated fully, he was granted discharge for disability.

Case 67. The patient, aged twenty-six years, had injured the right knee, playing football, at the age of sixteen years. There had since been intermittent swelling and pain. Roentgenograms showed five loose bodies in the suprapatellar pouch and one in the popliteal space. At operation, marked chondromalacia of the patella was found. The loose bodies were in distinct pockets in the suprapatellar pouch. The patella was smoothed, and four loose bodies were removed; the last one in the anterior chamber could not be located. The patient returned to duty, and complained only of occasional catching. One year later, a second attempt was made to locate the final loose body in the anterior chamber, but it slipped into the posterior chamber. At operation, roentgenograms taken with a portable machine did not locate it, and it has given no further trouble. Exploration showed the patella to be smooth, and the cartilage to be of good color and well regenerated, with no evidence of chondromalacia. No evidence of damage to adjacent femoral cartilage was found.

Case 96. The patient, aged eighteen years, had an operation to remove an area of recent osteochondritic involvement from the bearing surface of the femur. Subsequently he complained of inability to drill. An attempt was made to discharge him as being below the minimal standards. Because of his value as a secretary, he was retained in Service, but was not required to drill or do other physical work. Recently, his commander stated that he did not see why there had been so much fuss to keep this man from doing physical work, since in the evening he was one of the outfit's best basketball players.

Case 125. The patient, aged nineteen years, had chondromalacia of the patella only. Operation produced no subjective improvement. He was from the Air Corps, and was returned to his own field in the hope that work which interested him would be found. He had full motion of the knee and no swelling. It is believed that this man will ultimately receive a discharge.

Return to duty of the first four patients with osteochondritis dissecans was believed better than could be expected from a larger series. The continuance of good results was a gratifying surprise. With the exception of the patient with the acute case, all these men preoperatively were carrying on full duty, with a complaint only of catching due to a loose body. The old irregularity of the articular surface appeared to be of minor importance. In the light of our present knowledge, these cases will continue to be treated by surgery.

It is an old cliché that anything can be proved by figures. The cases in Class II, grouped under "erosion of the under side of the patella (chondromalacia)", are the only glaring instances where the separation of this series into classes distorts the results. Actually no case was diagnosed preoperatively as chondromalacia of the patella. Swelling and pain, coupled with the finding of tenderness on tapping the patella or pressing around its edges, have often suggested the diagnosis, as has grating on patellar movement. The diagnosis before operation has usually been a torn meniscus or a loose body. In the eleven

TABLE III

CLASS III. CASES SHOWING SEVERE ARTHRITIS[1]

Case No.	Associated Pathology			Disposition	Comment
	Loose Bodies	Torn Meniscus	Cruciates Torn		
Group 1					
39	3			Limited duty[2]	Loose bodies removed.
45				Limited duty. Discharged as unskilled	Old fracture of the patella; patella removed. Some lessening of pain on movement.
70	12	Yes	Yes	Discharged as unskilled	Slightly improved by operation. Meniscus and loose bodies removed.
71	1	Yes	Yes	Discharged as unskilled	Menisci and loose bodies removed; full motion present.
Group 2					
97				Disability discharge	Arthritis of the patella and femur; adhesions of fat pad to tibia. Patella smoothed and fat pad removed. Patient had a mild tourniquet paralysis. Final result, no essential change from condition before operation.

[1] The postoperative follow-up was 4.5 months.
[2] This patient has probably been discharged, but no record is available.

cases, six have shown meniscus injury; five, including three with injury to the meniscus, have had loose bodies; and in only three has the patellar defect been the only finding. Eight patients remain on duty, while one other, listed as on duty, will probably be discharged.

These cases are difficult to evaluate. I believe this condition is more often an accompaniment of old knee injuries than has been generally reported. In spite of the fact that two-thirds of our patients are still on duty, I do not believe that, if a preoperative diagnosis of chondromalacia of the patella is made, the operation should be done in the Military Service. If the condition is found at operation, the patellar cartilage should be smoothed. Removal of the patella is not a suitable procedure in the Army. Regardless of the result obtained, it is probable that the psychological effect would preclude the returning of most men to duty.

Table III, summarizing the cases in Class III, is self-explanatory. A man having arthritis of the knee of more than minimal severity cannot perform military duty. Each of these men had undergone combat training and had entered the hospital with a completely disabled knee. In each instance, the condition was undeniably aggravated in Service, and operation was undertaken to obtain the maximum benefit of hospitalization. The fact that not one of these five men is believed to be now in the Service is a warning of the danger of inducting a man with an arthritic knee.

The results of treatment in the few cases of fracture in the region of the knee joint show the difficulty experienced in returning men with these fractures to duty, especially those with fractures of the tibial plateau (Table IV). The failures are not entirely explainable on the basis of the injury alone. Wherever it has been necessary to immobilize a knee postoperatively for any length of time, atrophy of the thigh and limitation of motion have been the result. It has not been felt that the limitation has been sufficient in any

TABLE IV

CLASS IV. FRACTURES

Case No.	Type of Fracture	Disposition	Comment
		Group 1[1]	
2	Tibial spine	Duty[3]	Held with vitallium screw.
8	Tibial plateau	Disability discharge	Patient also had peroneal-nerve injury. Plateau held by screw. Arthritis developed. Foot-drop persisted.
30	Tibial spine	Duty[3]	Fragment sutured in place. Tourniquet paralysis developed. Excellent recovery.
31	Tibial spine	Limited duty	Fragment sutured in place. Patient has limitation of flexion to 75 degrees, and marked atrophy of thigh.
51	Compound fracture of patella	Disability discharge	Small, lower-pole fragment removed. Patient also had compound fracture of the ankle. Discharge was granted for this, not for knee.
74	Medial plateau of tibia	Disability discharge	Fixation by screw. Patient had many complaints. There was full extension, flexion to 75 degrees. Roentgenograms showed mild traumatic arthritis.
		Group 2[2]	
76	Fracture of the medial plateau with dislocation of the knee	Disability discharge	Good reduction, but marked loss of motion. Fixation by screw.
80	Fracture of the patella	Duty[3]	Patella was wired; it was refractured at seven weeks in a fall from the bed and required rewiring.
89	Old fracture of patella with malunion	Full duty	The lower fragment (one-fourth of the bone) was removed.

[1] The postoperative follow-up of the patients was 12.5 months.
[2] The postoperative follow-up of the patients was 7 months.
[3] The soldier is known to be in a job not requiring maximum use of the knee.

instance to warrant quadricepsplasty, but, in several instances, it made return of the patient to duty difficult or impossible, in spite of prolonged physiotherapy. Case 74 illustrates other factors complicating the results.

CASE 74. The patient, aged forty-two years, had been in Service two months when he fractured the medial table of the tibial plateau in a twelve-foot fall from a pole. This man had had no previous pole-climbing experience. The meniscus was removed, and a screw was used to hold the tibial plateau in place. He obtained full extension and flexion to 75 degrees. There was 2.5 centimeters (one inch) of atrophy of the thigh and no lateral instability. Roentgenograms showed an excellent reduction. This man was a model hospital patient, but, on return to duty, he became a disciplinary problem. I believe his age and fear of further injury, as well as residual disability, underlay his difficulties. A man desirous of continuing in the Service would have done duty with the knee condition present. In this man, however, the disability was sufficient basis for a disability discharge.

Few purely exploratory operations have been done (Table V); fewer should be done in the future. Exploration in each case was thorough, and the one patient granted a disability discharge did have considerable difficulty clinically. The three patients marked "duty" are not good soldiers. They have been seen many times with many complaints. Probably one man (Case 22) would have been under treatment in civilian practice. These patients illustrate how frequently psychoneurosis is found in the Army, and the necessity of making as definite a diagnosis as possible before operation. If a diagnosis cannot be made, disposition should be accomplished without exploration.

In Class VI are grouped the cases which might be called unusual. Careful watch

TABLE V

CLASS V. EXPLORATORY OPERATIONS [1]

Case No.	Complaint	Finding	Disposition	Comment
		Group 1		
43	Indefinite knee complaint	None	Duty [2]	Exploration only. Patient has had no further knee complaints, but has been in hospital since for stomach complaints. There were no organic findings. Diagnosis was mild neurosis.
13	Right knee "comes out of place"	Relaxed anterior end of lateral meniscus	Full duty	Meniscus was removed. There were no objective findings, but patient still says something "comes out" on lateral side.
22	Knee cap "pops" out of place	Torn medial meniscus	Disability discharge	Meniscus was removed, and Campbell's operation was performed to prevent possible dislocation of the patella. Patient cooperated, but knee continued to swell at intervals. Dislocation was never demonstrated, but there was much grating of the knee. Condition was essentially unchanged by operation. Patient was discharged because of mild, symptomatic arthritis.
		Group 2		
116	Locking knee	Questionable tear of medical meniscus	Full duty	Meniscus was removed and knee was explored. He later complained of hip pain, but there were no findings. The final diagnosis was mild psychoneurosis.

[1] Postoperative follow-up was 12 months.
[2] The soldier is known to be in a job not requiring maximum use of the knee.

TABLE VI

CLASS VI. UNUSUAL CASES [1]

Case No.	Complaint	Findings	Disposition
85	Both knees painful, right knee locks.	Fibrous mass, 5 by 1.8 × 1.8 centimeters, loose in the intracondylar area of the right knee; left knee was negative.	Limited duty
106	Mass in region of lateral ligament.	Fibrous mass, 2 by 1.5 × 1.0 centimeters, attached to the lateral meniscus.	Full duty
117	Tumorous mass beneath the patella. The mass was painful. (Patient had had 2 previous operations.)	Hemangioma involving the fat pad and invading the patellar ligament.	Full duty [2]

[1] Postoperative follow-up was 3.4 months.
[2] The soldier was on full duty when he left Camp Crowder, but the author doubts that he will be able to do full duty.

has been kept for discoid cartilages, cysts of the cartilage, and tumors of the synovial membrane.

CASE 85. The patient, aged nineteen years, complained of pain in both knees and locking of the right one. A white, sausage-shaped mass was removed from the right knee; it was not attached to the synovial membrane. Clinically, it appeared fibrous, but, on microscopic examination, showed cartilage and fibrous tissue. The knee was otherwise normal. Exploration of the left knee was carried out because of the findings in the right. No abnormality was found.

CASE 106. The patient, aged nineteen years, gave a history of severe, twisting injury to the knee, which

had occurred six years before operation and had kept him in bed for one month. He complained of swelling on the lateral aspect of the knee. On examination, there was a hard mass in the region of the fibular collateral ligament, and, in the roentgenograms, a wide interspace was noted on the lateral side. At operation, a fibrous mass 2 by 1.5 by 1.0 centimeters, found attached to the lateral meniscus, was removed, together with the meniscus. Six months later, he had slight swelling of the knee, full motion, no atrophy, and no abnormal mobility. In the pathological examination, unfortunately, the mass was ignored, and only the findings in the meniscus were reported.

CASE 117. The patient, aged twenty-four years, had had a tumor removed from the region of the left knee at the age of six years. This had recurred and had been again removed at the age of thirteen years. Thereafter, swelling had appeared whenever the knee was bruised. On examination, there were two operative scars medial to the patella, and a swelling, which felt cystic, was noted in this area. A larger mass could be felt beneath the patella. At operation, the tumor was found to involve the old scar and the fat pad, and to have infiltrated the patellar tendon. Except for a small portion in the tendon, which could not be obtained without removal of the tendon, the tumor was removed completely. A defect in the capsule, 2.5 centimeters (one inch) square, was created, which could only be closed with a free fascia graft. The cast was removed after thirty days. Five months after operation, the patient had full extension, and flexion to 95 degrees. The only excuse for this operation was that the man appeared to be of military value. He returned to duty in spite of his residual disability.

SUMMARY

In 150 consecutive knee arthrotomies, 105 cases showed injury only to the menisci, ligaments, or fat pad. Eighty-six torn medial menisci and fifteen torn lateral menisci were removed. Two cases showed tearing of both menisci. Fifty-four bucket-handle, twenty anterior, ten posterior, and three minimal tears (loose anterior attachments) are recorded. In the remaining cases, no accurate description of the portion of the meniscus injured is recorded. In this group of patients, ninety-seven returned to some type of duty.

In twenty-four cases, disorders of the bone and articular cartilage were shown. Of nine patients with osteochondritis dissecans, eight are believed at duty, while of eleven patients with chondromalacia of the patella, eight are probably still in Service.

Only five patients with severe arthritis were operated upon, and none of them are believed to be in the Army at present.

Nine patients with recent or old fractures involving the patella, tibial spine, or tibial plateau were operated upon. Five of these men have been returned to duty. Three men with fractures of the tibial plateau have been discharged for disability. The last man of the group was discharged for an ankle disability.

Of the remaining patients in the series, those operated upon primarily for diagnosis have shown poor results, the final diagnosis in most cases being psychoneurosis. Three unusual cases were found, and have been described in detail.

CONCLUSIONS

Patients with tears of the menisci, I believe, are suitable for operation in the Army, and a high percentage of these patients return to duty. The presence of injury to a cruciate ligament does not markedly alter the recovery rate, but the presence of injury to one of the collateral ligaments, or of chondromalacia of the patella gives a poor prognosis. Where diagnosis of these latter conditions is made preoperatively, operation should not be undertaken in the Military Service.

Cases showing loose bodies are suitable for operation, provided the only articular defect noted is that of an old osteochondritis dissecans. The presence of arthritis of the knee of any degree, shown either clinically or by roentgenogram, makes it unwise to operate, unless the man is of extreme military value.

Fractures of the tibial plateau offer a poor prognosis as to return of the soldier to military duty.

Finally, it is my conclusion that the majority of our mistakes have arisen from overenthusiasm and from lack of appreciation of the rigors of military service to which a man must return.

A METHOD FOR STUDYING HEALING OF BONE *

BY ALFRED MARSHAK, PH.D., AND R. L. BYRON, JR., M.D.,
BERKELEY, CALIFORNIA

From the Radiation Laboratory and the Division of Surgery of the University of California

INTRODUCTION

The methods commonly used in studying the healing of bone leave much to be desired. Studies employing roentgenograms, histological sections, clinical impressions, the experimental breaking of bones, *et cetera*, have added to the understanding of the healing of fractures, but each method has certain disadvantages.

In order to study better the metabolism of strontium and phosphorus in healing bone, radiostrontium† (Sr^{89}) and radiophosphorus† (P^{32}) were used. Radiostrontium was chosen, because, in the Periodic Table, it is closely related to calcium and behaves physiologically in a manner similar to that substance, but, for technical reasons, is more convenient to use than radiocalcium (Ca^{45}). Chemically and physiologically, radiostrontium and radiophosphorus behave identically with the non-radio-active substances, and have the advantage that they can be used in "tracer" doses,—that is, in amounts that can be identified readily, but do not influence normal physiological processes. Both radiophosphorus and radiostrontium give off beta particles of approximately the same energy value, which can be measured easily with a Geiger-Müller counter.

Methods were devised to determine the uptake of phosphorus and strontium by healing bone, by means of which it was possible to study the changes in the mineral metabolism from day to day, the relationship between phosphorus and strontium, and the effects of age on the healing of bone. These investigations were made *in vivo* on rats; with certain modifications they could be applied to studies on the healing of bone in man.

Cohen and Greenberg studied the uptake of radiophosphorus by bone in rats, particularly in relation to vitamin D_1. Treadwell and her associates studied the uptake of radiostrontium by normal and malignant tissues in human beings, and found that the strontium was retained wherever new tissue was being formed. Pecher showed that strontium, like calcium, is concentrated in the skeleton. The relative amount of radiocalcium and radiostrontium in bone and muscle was approximately the same for both elements, although the retention of calcium was greater than that of strontium. He found that, in mice, radiostrontium and radiophosphorus were taken up by normal bone in the ratio of 2.3 to 1, which is in close agreement with the mean ratio of 2.6 to 1, found in our studies of adult rats (Table I). The rate of calcification in the healing of fractures in guinea pigs and rats has been studied by histological methods by Hertz and by Urist and McLean.

METHODS

Attempts to produce uniform fractures of the tibia of the rat proved unsuccessful. It was found, however, that uniform defects in the tibia could be obtained by the use of a motor-driven circular saw. An incision from 2 to 4 centimeters in length was made in the skin of the outer surface of the leg, parallel to the tibia, and the skin was dissected away from the fascia covering the muscle until the tibia was exposed. By sharp dis-

* The work described in this paper was done under a contract recommended by the Committee on Medical Research between the Office of Scientific Research and Development and the University of California.

† The terms radiostrontium and radiophosphorus are used in place of the more lengthy terms radio-active isotope of strontium or phosphorus or radio-active strontium or phosphorus.[4]

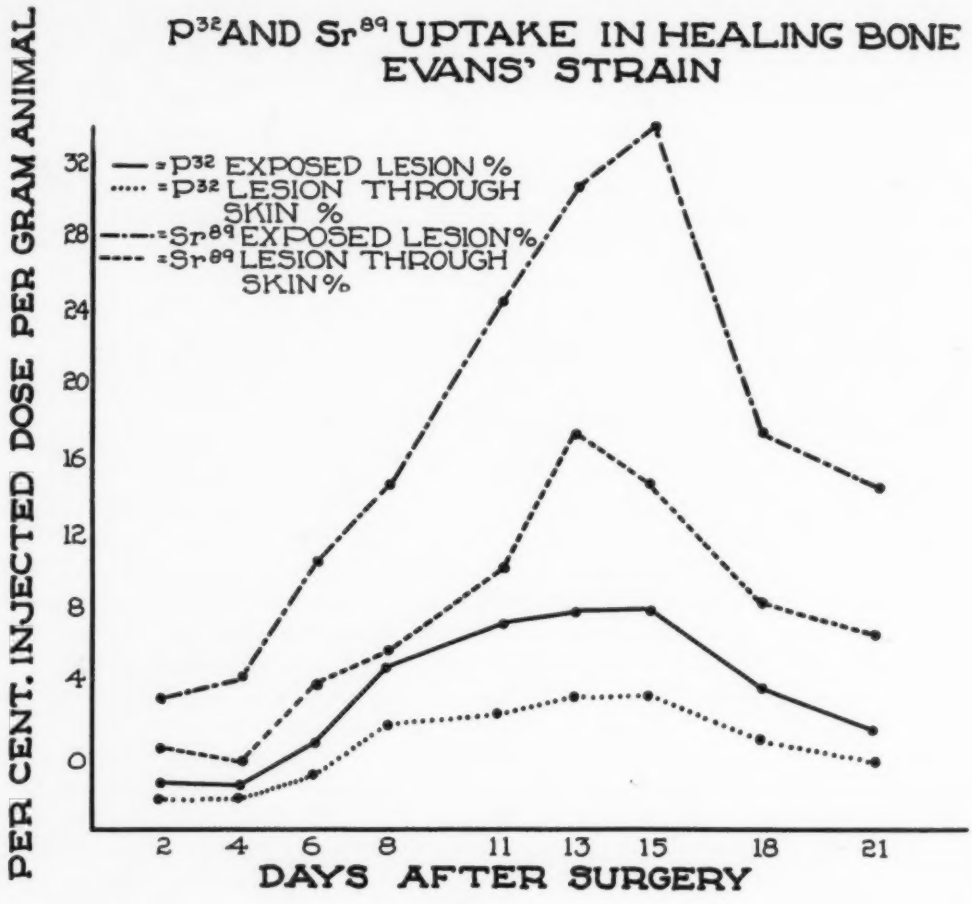

FIG. 1

section, the anteromedial aspect of the bone was then cleaned of muscle. With the saw, which was 6 millimeters in diameter by 0.75 of a millimeter in thickness, a cut was made, parallel to the long axis of the tibia, in the middle of the anteromedial surface, with the center of the cut at the level of the tibial tuberosity. Depth was controlled by allowing the saw to penetrate until its axis touched the surface of the bone. The distance from the shaft to the perimeter of the saw was 2 millimeters, so that the depth of the cut made was somewhat less than 2 millimeters. The cut extended through the marrow, but not into the cortex on the opposite side. The wound was cleansed of debris by irrigation with sterile saline or Ringer's solution, and the skin was closed with a continuous suture. After recovery from anaesthesia, the animals walked without apparent discomfort. In all cases, the radio-active solution (radiophosphorus as sodium acid phosphate or radiostrontium as strontium chloride) was given intraperitoneally 24 hours before measurements were made.

To shield the Geiger-Müller counter from beta particles other than those originating in the wound or its immediate vicinity, a lead plate with an aperture, 2 by 5 millimeters, was placed on the leg over the position of the wound. Some practice is needed in locating the bony lesion through the skin, although it usually can be felt either as a depression in the early stages, or as a slightly raised callus later. Several readings were taken, the lead shield being removed and reset each time to check for accuracy of the readings. The incision was then opened, the skin was retracted to expose the bone lesion, and the readings were taken with the aperture directly over the lesion. Similar readings were taken over the normal contralateral tibia.

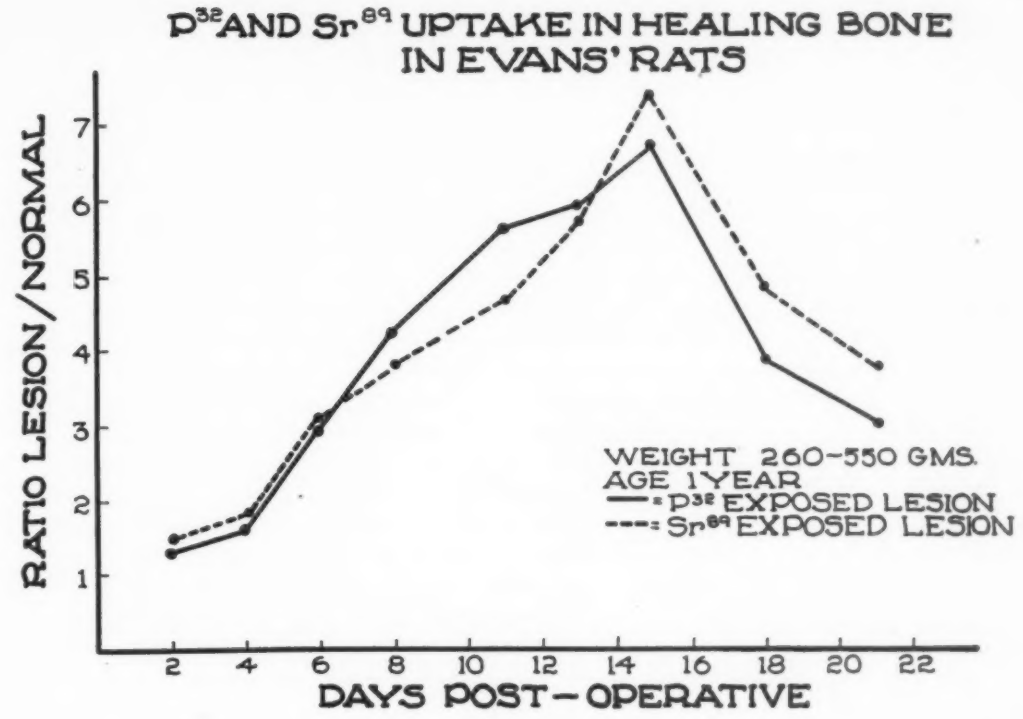
P32 AND Sr89 UPTAKE IN HEALING BONE
IN EVANS' RATS
RATIO LESION/NORMAL
1
2
3
4
5
6
7
2 4 6 8 10 12 14 16 18 20 22
DAYS POST-OPERATIVE
WEIGHT 260-550 GMS.
AGE 1 YEAR
—= P32 EXPOSED LESION
---= Sr89 EXPOSED LESION

FIG. 2

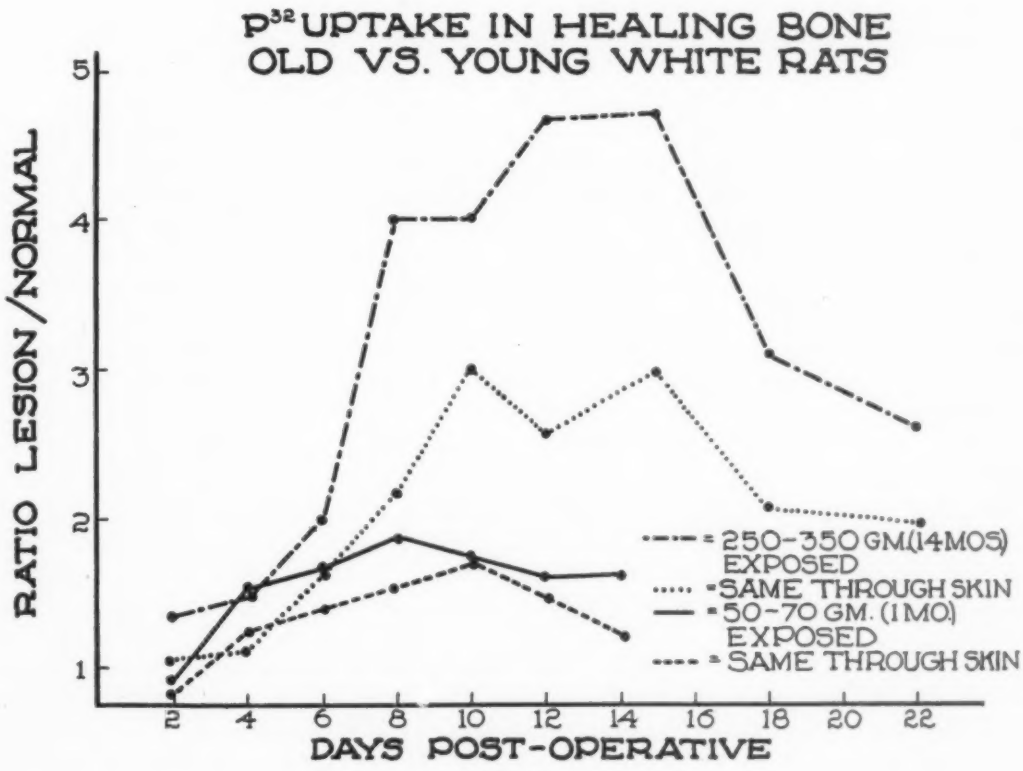
P32 UPTAKE IN HEALING BONE
OLD VS. YOUNG WHITE RATS
RATIO LESION/NORMAL
1
2
3
4
5
2 4 6 8 10 12 14 16 18 20 22
DAYS POST-OPERATIVE
-·-·- = 250-350 GM.(14 MOS.) EXPOSED
····· = SAME THROUGH SKIN
—— = 50-70 GM. (1 MO.) EXPOSED
---- = SAME THROUGH SKIN

FIG. 3

P^{32} has a half-life of 14.3 days, and Sr^{89} of 55 days. Allowance is made for this difference in calculations of the radio-activity in the lesion and in the normal bone as percentage of the injected dose per gram. Radiation effects on tissue are considered negligible, because of the small dose and the short time interval (24 hours) between injection and measurement. In experiments where the radio-active elements are in the tissue for more prolonged periods, such effects may have to be taken into account.

The Geiger-Müller tube used for measuring the radio-activity was completely sealed in glass and had a thin glass window approximately 5 centimeters (2 inches) in diameter. It had a 400-volt plateau which assured independence of fluctuations in the line voltage. A scale of eight counting circuit was used, and the eighth pulse from the tube activated a mechanical counter, so that the counts for each reading were automatically recorded. Before the tube was used in the experiments, it was checked with a cathode-ray oscillograph for uniformity in amplitude and for shape of the discharges (pulses). To minimize the amount of stray radiation (background), the tube was mounted inside a box with lead walls 5 centimeters (2 inches) thick. The lid and one side wall were hinged, so that the box could be opened at the side and top to introduce the animal and to orient the counter over the lesion or bone. Inside the box, the tube itself was encased in a brass cylinder, with walls 0.3 of a centimeter (1/8 of an inch) thick, to protect it from radiation originating from portions of the animal other than the region under investigation. The brass cylinder was mounted on a rack and pinion, so that it could be raised and lowered or fastened at any one position by the adjustment of a pair of knurled knobs. As previously mentioned, a lead plate was used to admit radiation into the counter window only from the 2-by-5 millimeter aperture over the lesion or normal bone. The anaesthetized rat was held on a block of wood, with the lead plate in position over the lesion. The block was then oriented, so that the aperture in the lead plate was centered under the counter; the cylinder holding the counter was then brought down in contact with the plate; and readings were taken.

Background readings were always taken before and at the end of the readings from the animals. These readings agreed to within a few per cent., and amounted to about 30 counts per minute. As a precaution against the possibility of a change in its characteristics, the tube was checked against a uranium-oxide (U_3O_8) standard each day before readings were taken on the animals. Readings on the standard agreed within 1 to 2 per cent., so that the repeated readings over the lesion and bone, mentioned previously, were primarily a check on the accuracy of orienting the aperture of the lead plate over the lesion.

Since the number of counts obtained over the lesion or bone varied from 200 to 7,000 per minute, it was necessary that determinations of the counting efficiency of the tube be made over the range of rates encountered. The tube was, therefore, calibrated against a series of standards containing various amounts of U_3O_8. Since there is a possibility of error with the larger amounts of U_3O_8, due to "self absorption", the tube was also calibrated against a series of carefully measured amounts of Na_2HPO_4 containing P^{32}, prepared by dilution and evaporation to the dryness of a single original solution of the phosphate. The calibration curve thus constructed covered a counting range of from 30 to 8,000 counts per minute. The counting rate observed was directly proportional to the amount of radio-activity up to a rate of 1,200 counts per minute. Above this rate, corrections were needed, the maximum corrections used being 14 per cent.

An additional precaution may be mentioned. In experiments other than those described here, it was necessary to use counter tubes closed off at one end with a stopcock. These tubes showed no sign of leakage, and maintained uniform counting characteristics for several weeks. However, when they were used on animals anaesthetized with ether, they changed their characteristics and lost their plateaux within 10 minutes. This diffi-

culty disappeared when nembutal was used for anaesthesia. Apparently ether enters the counter through the stopcock grease.

The amount of radio-activity in the lesion and the comparable area of the normal contralateral bone was calculated as follows:

1. The background reading was subtracted from the reading over the bone or lesion, and this value was corrected for counter efficiency from the calibration curve of the counting tube.

2. The animals in any one group were not of uniform weight. Instead of adjusting the dose injected to the weight of each animal, it was assumed that all rats were of standard weight,—that is, 400 grams for adult and 50 grams for young rats. The adult rats received 8 times as much of the radio-active isotope as the young; this was, however, the same dose per gram of weight. To correct for the variations in weight within each group, the reading, corrected for background and counter efficiency, as described, was multiplied by the ratio of the actual weight of the animal to the standard for the group.

3. The number of counts in the injected dose was determined from a series of standards made of carefully measured amounts of different dilutions of the solution injected.

4. The corrected reading over the lesion was then divided by the number of counts in the injected dose, allowance, of course, being made for decay. This gives the radio activity in the lesion as percentage of the injected dose.

5. Instead of using as a basis for comparison the injected dose per animal, which was 8 times as great in the adult as in the young rats, the injected dose per gram rat, which was the same for both groups, was used. The values so obtained are the ones shown in the tables and graphs.

The relation between the per cent. injected dose and the per cent. injected dose per gram may be illustrated as follows:

R = corrected reading in counts per minute;

I = injected dose in counts per minute;

W = weight in grams of the animal (group standard);

$$\text{Per cent. injected dose} = \frac{R}{I} \times 100 = P_1;$$

$$\text{Per cent. injected dose per gram} = R \div \frac{I}{W} \times 100 = \frac{R}{I} \times 100 \times W = P_1 \times W = P_2.$$

In other words, the per cent. injected dose per gram rat is the per cent. injected dose multiplied by the standard weights for each group.

6. The values for the ratios L:N and EL:EN are obtained directly from the readings, corrected only for background and counter efficiency, since the other corrections apply to both numerator and denominator.

RESULTS

The data are tabulated in the following tables in which L is the reading over the lesion before exposure, N the reading over the normal tibia before exposure, and EL and EN are, respectively, the readings from the exposed lesion and the exposed normal bone.

The data presented in Table I are from animals which received 1 milligram or less of strontium chloride and sodium acid phosphate (tracer dose).

Table II shows the result of injections which exceed tracer doses. Because the specific activity,—that is, Sr^{89} per gram of strontium chloride—was low, these animals received 17.6 milligrams of strontium chloride. The lower percentage of retention in the bone is probably due to greater excretion when excessive amounts of strontium chloride were used. It is clear from comparison of columns EL in Tables I and II that the percentage of the injected dose per gram retained in the lesion after the excessive dose

TABLE I

COMPARISON OF THE UPTAKE OF RADIOPHOSPHORUS AND RADIOSTRONTIUM BY HEALING BONE IN RATS (EVANS'S STRAIN), ONE YEAR OLD, WEIGHING 260 TO 550 GRAMS

Post-operative Days	Radiophosphorus (P^{32})				Radiostrontium (Sr^{89})				Sr^{89}:P^{32}	
	L*	EL*	L:N*	EL:EN*	L*	EL*	L:N*	EL:EN*	EL*	EL:EN*
2	1.74	3.04	0.85	1.24	2.88	5.27	1.01	1.35		
	1.74	2.16	0.95	1.07	3.37	5.74	1.08	1.25		
	1.74	3.16	1.20	1.78	5.06	8.15	1.45	1.67		
	1.61	2.11	1.02	1.00	5.74	10.70	1.35	1.72		
					4.85	6.15	1.61	1.47		
	1.71	*2.62*	*1.01*	*1.27*	*4.38*	*7.20*	*1.30*	*1.49*	2.75	1.17
4	1.92	2.94	1 07	1.47	2.97	5.94	1.01	1.17		
	1.87	2.91	1.84	2.22	3.48	6.43	1.09	1.55		
	1.88	2.42	1.40	1.62	4.54	9.31	1.75	1.90		
	1.82	2.16	1.49	1.41	4.16	11.10	1.95	2.50		
	1.58	1.77	1.18	1.23						
	1.81	*2.44*	*1.38*	*1.59*	*3.79*	*8.22*	*1.45*	*1.78*	3.36	1.12
6	2.95	4.80	2.11	3.38	9.56	14.00	2.92	2.96		
	2.96	4.59	2.32	2.92	8.98	17.72	1.52	2.45		
	4.23	5.11	1.84	1.88	8.20	15.93	1.93	3.65		
	2.68	5.29	2.00	4.23	8.26	12.50	2.78	2.30		
	2.45	4.60	1.63	2.83	5.31	10.26	2.03	2.78		
	2.70	3.97	1.81	2.20	6.81	15.00	2.69	4.28		
	3.00	*4.73*	*1.99*	*2.91*	*7.85*	*14.24*	*2.31*	*3.07*	3.02	1.05
8	4.08	7.34	2.40	3.10	10.85	22.46	4.33	4.37		
	7.54	11.17	4.11	5.35	14.60	29.20	5.52	7.11		
	7.16	7.95	4.56	4.12	7.14	11.16	2.82	2.48		
	5.07	9.66	3.05	4.72						
	4.77	8.56	3.51	6.29						
	5.72	*8.94*	*3.53*	*4.72*	*10.87*	*20.94*	*4.22*	*4.65*	2.34	0.99
11	5.20	10.24	3.86	6.82	12.24	21.35	2.53	3.36		
	7.22	13.86	3.79	5.39	17.22	32.30	3.29	4.86		
	6.50	9.89	4.69	6.66	15.85	31.40	4.14	5.74		
	5.00	8.14	3.37	4.88						
	6.16	10.68	3.87	6.33						
	†5.34	7.99	2.58	3.50						
	5.90	*10.13*	*3.69*	*5.60*	*15.10*	*28.35*	*3.32*	*4.65*	2.80	0.83
13	7.24	11.75	4.28	5.79	24.73	41.60	6.32	6.75		
	6.02	10.23	4.16	5.98	21.90	30.26	6.50	5.35		
	4.98	8.89	3.94	5.20	17.58	31.80	3.54	5.00		
	8.24	11.37	4.61	4.86						
	5.69	10.07	4.88	7.55						
	5.84	8.79	4.00	5.54						
	6.34	*10.19*	*4.31*	*5.82*	*21.40*	*34.55*	*5.45*	*5.70*	3.39	0.98
15	5.10	7.98	3.24	4.88	20.10	50.50	9.26	11.23‡		
	12.32	18.10	5.68	7.28	14.20	27.70	3.14	4.11		
	8.32	15.27	6.31	7.77	21.50	35.30	3.67	5.09		
	5.55	8.60	3.38	3.81	15.03	29.20	5.26	8.82		
					15.95	32.30	5.93	6.94		
					9.66	23.45	4.97	7.24		
					16.48	36.38	6.13	8.94		
					12.51	26.10	6.94	7.88		
					14.13	30.60	6.11	7.47		
					16.09	23.27	6.41	7.43		
	7.82	*12.49*	*4.65*	*5.94*	*15.57*	*31.48*	*5.78*	*7.52*	2.52	1.27

TABLE I (continued)

Post-operative Days	Radiophosphorus (P^{32})				Radiostrontium (Sr^{89})				Sr^{89}:P^{32}	
	L*	EL*	L:N*	EL:EN*	L*	EL*	L:N*	EL:EN*	EL*	EL:EN*
18	4.42	8.86	2.15	3.46	12.87	22.40	4.98	5.45		
	5.42	6.72	3.06	4.19	11.42	18.33	4.66	4.76		
					12.82	23.33	2.82	4.00		
	4.92	*7.79*	*2.61*	*3.83*	*12.37*	*21.35*	*4.15*	*4.74*	2.74	1.24
21	2.79	3.40	1.92	2.31	10.45	20.20	3.00	3.99		
	4.31	6.72	2.90	3.68	9.80	14.57	1.92	2.13		
	4.35	6.64	2.26	2.81	11.83	21.50	3.58	5.08		
	3.82	*5.59*	*2.36*	*2.93*	*10.69*	*18.76*	*2.83*	*3.73*	3.36	1.2

* The values for L, N, EL, and EN used in all the tables and graphs are in percentage of the injected dose per gram rat.

† On inspection, lesion showed little sign of healing.

‡ Wound showed exceptionally large amount of callus.

The following calculations and their possible implication are presented merely as a further illustration of the usefulness of the technique.

The lesion is roughly 0.2 by 0.5 centimeters and, assuming a depth of 2.0 millimeters, has a volume of 0.2 by 0.2 by 0.5 = 0.020 cubic centimeters. For a specific gravity of about 1, this will be about 20 cubic milligrams of tissue. At the peak (the thirteenth day), 34.55 per cent. of the injected dose per gram rat was found in the lesion. This is 0.3455 by 10^3, or 345 per 100 milligrams, or about 17 times as much as would be expected, if the injected solution were distributed uniformly throughout the body and there were no excretion. If excretion is allowed for, the concentration in the lesion is even greater. Compared with this, the concentration in the lesion on the second postoperative day is only one-fifth, or about 3 times the concentration of the injected dose, if uniformly distributed. Since EL:EN on the second day is about 1.5, the normal bone has a concentration of 3.54:1.5 or about 2.4 times the injected solution.

of strontium chloride was only one-third or one-half that observed after the smaller dose. Nevertheless, the ratios of the readings over lesion and normal bone through undisturbed skin (L:N) and over the exposed areas (EL:EN) are similar in both sets of animals.

In the rats 1 month old (Table III), the radiophosphorus was given in tracer doses of less than 1 milligram of sodium acid phosphate, but it was found necessary to administer 4.4 milligrams of strontium chloride, which is in excess of a tracer dose. The data in Tables II and III cannot be used, therefore, to determine the absolute amount of strontium taken up by the bone under physiological conditions. Thus the ratio of radiostrontium to radiophosphorus does not represent the relative amount of each element

TABLE II

COMPARISON OF THE UPTAKE OF RADIOPHOSPHORUS AND RADIOSTRONTIUM BY HEALING BONE IN RATS (SLONAKER'S STRAIN), WEIGHING 250 TO 350 GRAMS

Post-operative Days	Radiophosphorus (P^{32})*				Radiostrontium (Sr^{89})†				Sr^{89}:P^{32}	
	L	EL	L:N	EL:EN	L	EL	L:N	EL:EN	EL	EL:EN
2	1.50	2.10	1.03	1.34	1.36	2.06	0.83	0.93	0.98	0.69
4	1.61	2.38	1.11	1.49	1.90	3.42	1.52	1.48	1.44	1.00
6	1.93	3.09	1.63	2.09	4.26	5.51	1.67	1.93	1.78	0.92
8	3.08	5.27	2.16	4.00	7.73	10.70	4.83	4.62	2.03	1.16
10	4.60	6.83	2.98	4.00	6.45	9.42	3.67	3.71	1.38	0.93
12	3.86	7.93	2.54	4.64	7.48	12.03	5.88	6.97	1.55	1.50
15	6.67	11.73	2.95	4.69	10.20	15.58	5.77	6.29	1.33	1.34
18	2.29	3.74	2.24	3.09	8.82	13.09	3.54	3.67	3.50	1.19
22	2.23	3.09	1.95	2.72						

* The values for postoperative days 2, 4, 10, 15, and 22 are means of three animals; and those for postoperative days 6, 8, 12, and 18 are means of two animals.

† All values are means of two animals except for postoperative days 10, 12, and 15, which are means of 3 or 4 animals.

TABLE III

COMPARISON OF THE UPTAKE OF RADIOPHOSPHORUS AND RADIOSTRONTIUM BY HEALING BONE IN RATS (SLONAKER'S STRAIN), ONE MONTH OLD, WEIGHING 50 TO 70 GRAMS

Post operative Days	Radiophosphorus (P^{32})				Radiostrontium (Sr^{89})				Sr^{89}:P^{32}	
	L	EL	L:N	EL:EN	L	EL	L:N	EL:EN	EL	EL:EN
2	1.52	3.86	0.41	0.91	2.24	3.76	0.82	0.90		
	3.31	2.87	1.32	0.80	2.07	2.80	0.64	0.77		
	1.83	2.64	0.80	1.16	2.24	3.77	0.60	0.90		
	1.50	3.04	0.55	0.95						
	2.00	3.36	0.90	0.83						
	2.03	*3.15*	*0.80*	*0.93*	*2.18*	*3.44*	*0.69*	*0.86*	1.09	0.93
4	2.01	5.05	1.19	1.21	2.80	3.57	1.33	1.20		
	3.39	5.56	1.07	1.54	2.89	4.44	1.35	1.48		
	4.07	5.94	1.24	2.10						
	2.58	3.98	1.32	1.19						
	2.79	4.06	1.38	1.46						
	2.97	*4.92*	*1.24*	*1.50*	*2.85*	*4.01*	*1.34*	*1.34*	0.82	0.90
6	4.14	6.52	1.30	1.75	1.97	4.96	1.77	1.93		
	3.72	8.83	1.04	1.82	2.99	4.99	1.43	1.41		
	3.88	6.21	1.81	1.69	4.32	5.60	1.22	1.60		
	2.72	5.60	1.24	1.39	4.48	6.16	1.42	1.48		
	2.69	3.46	1.84	1.81						
	2.17	3.33	1.09	1.31						
	3.22	*5.68*	*1.39*	*1.63*	*3.44*	*5.43*	*1.46*	*1.61*	0.96	0.99
8	2.94	6.62	1.44	2.11	4.56	6.27	1.59	1.95		
	4.68	5.81	1.93	2.06	4.44	8.33	2.95	2.59		
	5.05	5.87	2.08	1.79	7.13	8.51	1.78	1.94		
	3.18	5.91	1.09	1.55	6.87	8.20	1.86	2.00		
	3.92	5.55	1.15	1.48						
	3.12	4.48	1.48	2.23						
	3.44	5.29	1.43	1.83						
	4.20	5.83	1.79	1.82						
	3.60	5.96	1.55	1.84						
	3.79	*5.70*	*1.59*	*1.86*	*5.75*	*7.83*	*2.05*	*2.12*	1.36	1.14
10	2.47	5.14	1.78	1.91	8.44	12.50	1.67	2.20		
	3.36	5.79	1.49	1.42	5.22	8.91	1.91	2.25		
	2.46	3.53	2.50	1.60	7.05	9.80	1.77	2.23		
	6.10	0.30	1.59	1.82						
	5.87	8.07	1.24	1.35						
	4.33	6.68	1.80	2.24						
	4.19	5.31	1.69	1.75						
	3.50	4.37	1.48	1.74						
	4.04	*6.02*	*1.70*	*1.73*	*6.90*	*10.40*	*1.78*	*2.23*	1.73	1.31
12	3.31	4.30	1.46	1.39	5.72	7.61	1.39	1.58		
	4.02	5.71	1.42	1.61	6.60	9.24	1.97	2.08		
	3.10	6.35	1.42	1.52						
	4.72	7.63	1.54	1.79						
	3.79	*6.00*	*1.46*	*1.58*	*6.16*	*8.43*	*1.68*	*1.83*	1.41	1.16
14	4.51	6.95	1.36	1.95	5.99	7.05	1.94	1.48		
	3.23	5.92	1.12	1.58	6.54	7.11	2.00	1.41		
	1.79	3.99	1.12	1.30						
	3.18	*5.62*	*1.20*	*1.61*	*6.27*	*7.08*	*1.97*	*1.45*	1.26	0.90

that would be taken up under ideal tracer conditions. The change in this ratio as a function of the age of the wound, however, is indicative of changing conditions in the healing lesion.

In the young animals, the absolute rate of uptake (EL), as well as the relative uptake, is at a maximum on the eighth to tenth day after the lesion is made. In the older animals, the maximum is not reached until the fifteenth day. On visual inspection, the wounds in the young rats appeared to be healed by the tenth day, and could usually be located by the presence of a slightly raised white callus. In the old rats, the lesion was still not healed by the fifteenth day. It appeared as a fine brown line in a depression, with slightly raised callus on either side. The time it takes a wound to reach a maximum uptake of radiophosphorus or radiostrontium may, therefore, be used as a measure of the rate of healing. The values obtained from readings through undisturbed skin (L and N), and the ratios obtained from them (L:N), parallel those taken over the exposed lesion, thus making it possible to measure the rate of healing of a bone lesion without exposing it. Since the ratios L:N and EL:EN both increase by a factor of 4.5 to 5 in the course of the healing process (Table I), it should not be difficult to follow the effect of various agents on that process. Although the individual variations are rather large, marked deviations from the mean of the group usually can be accounted for. For example, the uptake of P^{32} at 11 days, shown by the ratio for EL:EN of 3.5 (Table I), was obtained from an animal whose wound was much retarded and appeared more like one in its sixth day; while the uptake of Sr^{89} at 15 days, shown by the ratio for EL:EN of 11.23 (Table I), was obtained from a wound with an excessive amount of callus.

Normal bone shows a higher percentage of uptake of radiophosphorus in young than in old animals, presumably because the young bone is growing. In the early stages of healing, there is little difference in the relative amount (EL:EN) of radiophosphorus taken up in lesions of the old and young rats; but in the later stages (from 8 to 15 days) there is about 3 times as much in the lesions of the old animals as in the young. This is simply an index of what may be observed by visual inspection,—that is, a greater quantity of osteoid tissue is formed in old as compared to young animals.

There is no apparent difference in the time at which uptake of radiostrontium by healing bone reaches a maximum, as compared to the uptake of radiophosphorus. It appears to be impossible by this method to detect a proliferation and calcification stage in the healing of bone. The percentage of radiophosphorus taken up in the lesion (EL), however, may be compared to the amount of radiostrontium similarly taken up. The ratio of radiostrontium to radiophosphorus may be calculated from the percentage uptake in the exposed lesion or from the amount in the lesion relative to normal bone (EL:EN). The values obtained by these procedures are listed in the last two columns in the tables. In Table I, the ratio of strontium to phosphorus in the exposed lesions varies from 2.3 to 3.4 with no obvious trend. This variability may be a reflection of the large range in weight of the animals used, which would not affect the ratio of EL to EN, but might be reflected in calculations in the percentage of uptake. It is probably also significant that these animals were not from an inbred strain. In Tables II and III, there is some indication of a trend to a maximum on the eighth to twelfth day. These animals were all from an inbred strain and their weights and ages were much more uniform.

If the relative uptake of radiostrontium and radiophosphorus is the same as for normal bone, the ratios of strontium to phosphorus obtained by the second method mentioned above,—that is, EL:EN strontium divided by EL:EN phosphorus, should give a constant value of 1. For the young rats (Table III), the ratio averages 0.94 for the first 6 days after operation and 1.13 from the eighth to the fourteenth day. Similarly, for old rats, the average ratio is 1.02 for the first 13 days, and 1.26 for the next 8 days (Table I). For the Slonaker strain of old rats (Table II), the mean ratios were 0.94 during the first period and 1.34 in the later stages of healing. Thus the calculations from these data show that relatively more radiophosphorus and less radiostrontium is taken up in the early stages of healing, as compared with the later stages. It should thus

be possible to distinguish between stages in the healing of bone in which proliferation predominates, as compared to stages in which calcification is predominant.

Where it is necessary to study the healing of deep-seated bone, the gamma-active radiostrontium Sr^{85} may be used by the same methods as those described for radiostrontium Sr^{89}.

SUMMARY

1. A method is described for making uniform lesions in the bone to permit a study of its healing.

2. A method of using radio-active tracers to study the healing of bone *in vivo* is described.

3. The uptake by healing bone of radiophosphorus and radiostrontium is determined at different stages in the healing process.

4. The uptake by healing bone of phosphorus and strontium is compared.

5. The effect of the age of the animals upon the uptake of phosphorus in the healing of bone is studied.

6. In young animals, the latent period for an increased uptake of phosphorus is shorter than in older animals (2 as compared with 4 days).

7. The maximum uptake of phosphorus and strontium occurs on the eighth to the tenth day in young rats, as compared with the maximum of 15 days reached in old rats. This parallels the gross healing of the old and young bones.

8. By comparing the ratio of uptake of strontium and phosphorus, it is seen that this ratio tends to increase later in the healing process; it may be possible to utilize this tendency to differentiate between the proliferating and the calcifying stages of bone-healing.

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THE INTERVERTEBRAL DISC: ITS MICROSCOPIC ANATOMY AND PATHOLOGY

Part I. Anatomy, Development, and Physiology

BY MARK B. COVENTRY, M.D., RALPH K. GHORMLEY, M.D., AND JAMES W. KERNOHAN, M.D., ROCHESTER, MINNESOTA

From the Section on Orthopaedic Surgery and the Division of Surgical Pathology, Mayo Clinic, Rochester

The clinical picture of backache has often been an enigma to the medical profession. Much excellent work has been done on the subject of backache, but there is much left to be discovered. Posterior protrusion of an intervertebral disc has only relatively recently been recognized as a clinical entity. As a factor in backache, its importance cannot be overstressed. A working knowledge of the anatomy and pathology of the intervertebral disc is especially important from this standpoint.

Most backache occurs in the region of the lumbosacral "joint". This region carries most of the strain of the spinal column, and, as has been stated by Goldthwait, half of the motion between the lower thoracic region and the sacrum takes place here. It is, therefore, logical that investigation of the intervertebral discs be centered in this region.

It is important to understand the evolutionary factors involved in the lumbosacral region. It is here that much in the way of "congenital defect" takes place, and individual variation is rather great. The evolution of this region has been fully summarized by Keith. His extensive work has brought to light the changes in structure and mechanics that have occurred as the species has evolved from the horizontal to the upright position.

TABLE I

Age Incidence of Specimens Studied

Age (*Years*)	Cases
0–10	5
11–20	6
21–30	8
31–40	9
41–50	11
51–60	22
61–70	16
71–80	11
Total	88

In order to shed some light on this complicated problem of backache, a microscopic study of the lumbosacral intervertebral disc has been carried out. Clinical symptoms or signs have not been used. Roentgenograms of the discs, with their adjacent vertebrae, have been taken, after removal at necropsy, in order to correlate the roentgenographic findings with the appearance of the same specimen through the microscope.

The first paper covers the method of study, the anatomy, the embryology, and the physiology of the intervertebral disc. Two subsequent papers will deal with (1) the changes to be expected within each age group—an attempt to establish a "normal" microscopic appearance—and (2) pathological changes in the intervertebral disc.

SOURCE OF MATERIAL AND METHOD OF STUDY

The material in this study was obtained during routine necropsy of eighty-five subjects. Three additional cases, taken at a somewhat later date, were also used to amplify

FIG. 1

Intervertebral disc of a man, aged fifty-four years. *A*: Cartilaginous plate. *B*: Annulus fibrosus. *C*: Nucleus pulposus. *D*: Bony rim. The arrows indicate the junction of the cartilaginous plate and the bony rim. *E*: Bony spur. (× 3.)

the study of pathological discs. Thus the total number of cases studied was eighty-eight. Fifty-one subjects were male and thirty-seven were female. The youngest subject was aged ten months; the oldest, seventy-nine years.

Table I shows the distribution of cases by decades.

After the specimens were removed from the spinal column, they were fixed in formalin, and then a lateral roentgenogram was taken. After this, the specimens were sectioned mid-sagittally with the band saw, and a thin sagittal section in turn was cut from one of the halves. This section was prepared for microscopic study by decalcification [8], imbedding in paraffin, and sectioning with the microtome. The microscopic sections were stained by three methods: (1) hematoxylin and eosin, (2) van Gieson, and (3) De Galantha's method for mucin.[7]

The prepared sections were studied microscopically, but much additional information was obtained by projecting the slide on a screen, and studying the disc as a whole in its grosser aspects, at a magnification of twelve diameters. Each section was of course carefully compared with its corresponding roentgenogram.

THE ANATOMY OF THE INTERVERTEBRAL DISC

There are twenty-three intervertebral discs in the normal spinal column. They make up, roughly, a quarter the height of the vertebral column. They are thinnest in the thoracic region and thickest in the lumbar region. We are especially concerned with the fifth lumbar disc, but the structure of all the intervertebral discs is relatively the same.

A. *Adjacent Vertebrae*

The vertebrae adjacent to the discs, that is, cephalad and caudad, are composed of a cancellous type of bone, with rather specialized bony plates of denser, smooth bone, situated superiorly and inferiorly. These bony plates are, however, simply a reflection of

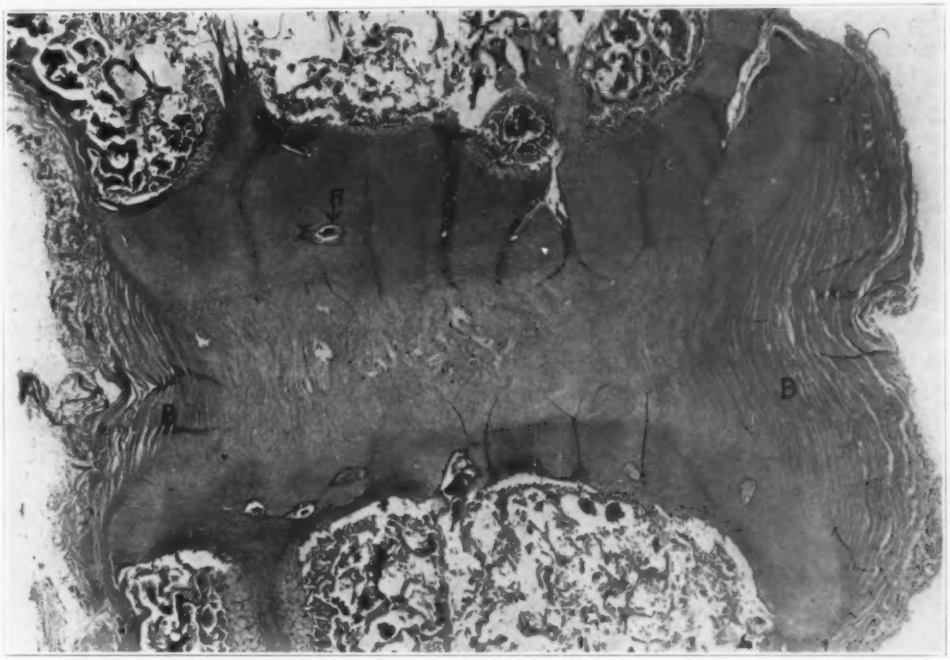

FIG. 2

Intervertebral disc of a girl, aged ten months. *A*: Vascular channel in the cartilaginous plate. *B*: Annulus fibrosus. (× 7.)

the spongy bone of the body of the vertebra, for they are perforated by many small holes corresponding to the marrow cavities. Each end plate is divided into three zones:

1. Central zone, with small, numerous holes.

2. Peripheral zone, with larger, less numerous holes. These perforations in the central and peripheral zones are probably for nourishment of the adjacent discs, as they allow fluid to pass from the spongy bone into the disc.

3. Epiphyseal ring, surrounding the outside of the end plate. It is raised and is composed of dense bone. This is the *Randleiste* of Schmorl; it was first described by Fick. Externally it overlaps the outer surface of the vertebral body, and internally it slopes to meet the peripheral zone of the bony plate.

B. *Ligaments*

The ligaments of the spinal column with which we are concerned are the anterior longitudinal and posterior longitudinal ligaments. They extend anteriorly and posteriorly on either side of the spinal column from the axis to the sacrum, and are intimately blended with the underlying intervertebral discs.

C. *Gross Anatomy of the Disc*

The intervertebral disc is like a cushion between the two adjacent vertebral bodies. It is composed of three rather distinct parts (Fig. 1):

1. *Cartilaginous Plate*: This structure of hyaline cartilage covers the bone of the vertebra, and acts as a limiting plate caudad and cephalad, with the fibrous disc proper in between.

2. *Annulus Fibrosus* (*Lamellosus*): This arises from the cartilaginous plates, surrounds the nucleus pulposus, and inserts into the anterior and posterior longitudinal ligaments and into the bone of the vertebrae. It gives the size and shape to the disc, and is the seat of most of its strength and tenacity.[2]

3. *Nucleus Pulposus:* This is the semigelatinous center of the disc, which is encapsulated by the annulus. It is a peculiarly active or dynamic portion of the disc, by reason of its turgescence.

D. *Blood and Nerve Supply to the Disc*

Übermuth, in 1929, and Böhmig, in 1930, expressed the belief that, up to the age of eight years, there are small blood vessels supplying blood to the disc by way of the cartilaginous plate. Übermuth further stated that these vessels begin to become scarred at the age of eight months, and scarring is complete at twenty to thirty years. These nutritive channels have also been described by Smith. The results of the present study tend to concur with these findings. Vascular channels with blood cells in their lumina are seen in the first three decades, but not as a rule following that time (Fig. 2).

Roofe, in 1940, found nerve endings in large amounts in the posterior portion of the annulus fibrosus and in the posterior longitudinal ligament. No specialized end organs were found in the authors' studies, but the type of terminal end organs indicated that they were probably pain fibers. No special nerve staining was done in our study. No fibers or nerve endings were observed with the routine stains.

E. *Microscopic Anatomy*

1. *Cartilaginous Plate*: The cartilaginous plates are composed of ordinary hyaline cartilage. They lie between the bone of the vertebrae and the fibrous components of the disc. The cartilage is found over the perforated bony end plate, but not over the compact peripheral zone or epiphysis. It is rather loosely cemented to the underlying bone by a very thin layer of calcium[10], which is absent at points corresponding to the perforations of the bony plate. The hyaline cartilage cells are arranged somewhat horizontally. The fibrocartilage of the annulus fibrosus takes its origin from the cartilaginous plates, as will be described later.

2. *Annulus Fibrosus* (*Lamellosus*): This structure is the "limiting membrane" for the nucleus pulposus. It is not entirely distinct from the nucleus, as the two tend to blend together. They are, none the less, separate structures. The annulus is the major part of the disc. It is composed of fibrous and fibrocartilaginous lamellae in an intricate arrangement. The fibers are of three groups: (1) those that "stream off" of the inner surface of the cartilaginous plates, where there is a gradual transition from hyaline cartilage to fibrocartilage; (2) those that pass anteriorly and posteriorly to insert into the longitudinal spinal ligaments, and (3) those fibers that pass over the edge of the vertebral body and sink into the bone of the vertebrae like Sharpey's fibers. The annulus is thought to be much stronger anteriorly, where the attachment to the longitudinal ligament is very strong, than posteriorly, where the attachment to the longitudinal ligament is much looser. The posterior ligament is also weaker than the anterior ligament. These facts may partially explain the much higher frequency of posterior than anterior protrusions of the disc.

The fibers of the annulus pass from the nucleus pulposus to the cartilaginous plate at right angles to the plate, but change their course and insert into the plate obliquely. Anteriorly and posteriorly the fibers are richly arranged in lamellae, and pass obliquely from the plate to the periphery in spherical fashion, turning up at the end to curve back to the opposite plate. Toward the periphery of the cartilaginous plate, the fibers pass out laterally from the end of the plate and divide into three groups. One group goes upward to the opposite plate, one blends into the fibers of the longitudinal ligament, and the third group, according to Beadle, "forms a small but pathologically very important system". It passes away from the disc, streams over the edge of the epiphyseal ring, and inserts into the bone of the vertebra, just as do the Sharpey fibers of the longitudinal ligaments. This is an important point, in Beadle's opinion, for it illustrates that the attachment of the disc

to the longitudinal ligaments, cartilage, and bone is stronger than is the attachment of the epiphyseal ring to the bone underlying it.

3. *Nucleus Pulposus*: When the disc is cut across horizontally, the tissue of the nucleus swells out as a white, glistening body, showing that the nucleus is normally under tension. The line of demarcation between the nucleus pulposus and the annulus is rather distinct in young subjects, becoming less so in adults. The nucleus usually occupies the region at the junction of the middle and posterior thirds of the disc.[5] It is formed of loose, wavy, fibrous strands in a liquid-saturated reticulum, which is gelatinous and mucoid. Notochordal remnants are said to be present at birth, and physaliferous cells of Virchow have been identified by some. These notochordal cells gradually diminish in number, and the nucleus becomes denser and more fibrous. In the adult disc, the nucleus pulposus contains cartilage cells and fibroblasts in a semigelatinous matrix. The fluid content of the nucleus diminishes from 88 per cent. in a full-term foetus to 66 per cent. in a seventy-seven-year-old subject, according to Püschel.

Various authors have described a central cavity in the nucleus, and some have compared it to a rudimentary joint cavity. There is no endothelial lining to these cavities, but villous-like processes can be seen to project into them. Others [4,23] have expressed the belief that these cavities are simply evidence of nuclear desiccation.

Whether there is true mucus in the nucleus pulposus is a somewhat controversial point. While this study reveals a distinctly mucoid reaction to hematoxylin and eosin stain, De Galantha's mucin stain does not show the presence of true mucus in any of the specimens. Deucher and Love were able, however, using mucicarmine stain, to get positive reactions for mucus in protruded discs removed during operation.

THE EMBRYOLOGY AND DEVELOPMENT OF THE INTERVERTEBRAL DISC

For proper interpretation of findings in the intervertebral disc and adjacent vertebrae, one must know something of the development of these structures. Excellent diagrammatic representations may be found in the work of Bradford and Spurling. The vertebrae, cartilaginous plate, and annulus fibrosus are derived from mesoderm. The nucleus pulposus is derived from endoderm, being in part a remnant of the notochord. Neither the primitive vertebrae nor the provertebrae correspond to the adult vertebrae. Each provertebra divides horizontally, and the caudad half attaches to the cephalad half of the adjacent provertebra. These halves unite to form the final rudimentary vertebra. The provertebra is marked off by the intersegmental artery, which is usually clearly seen in the spinal columns of young persons.

The intervertebral discs themselves apparently differentiate (or remain undifferentiated from the surrounding differentiating cells). As development proceeds, water leaves the cells, except in the region of the future intervertebral discs.[4] It has been postulated by Bardeen and Williams that this retention of water is due to the lack of nourishment to the region of the disc, as this region lies farthest from the intersegmental artery.

The notochord becomes extruded into the intervertebral regions as its canal gradually closes. At the end of the tenth embryonic week the cells of the vertebral bodies have become cartilaginous in type, and the cells of the notochord lie entirely within the disc, and can then be called nucleus pulposus. These cells undergo mucoid degeneration. They remain as notochordal-type cells until after birth, when they gradually disappear. The hypothesis of Dursy and Virchow, that the chief source of the nucleus pulposus was degeneration of the annulus fibrosus, has been disproved. There is no question that the primitive notochord is the anlage of the nucleus pulposus. Keyes and Compere emphasized the rather sharp line of demarcation, especially in the spinal columns of young persons, between the annulus fibrosus and the nucleus pulposus, which, they stated, is caused by a ring of fibroblastic tissue in the embryo. The persistence of notochordal cells up to the time of birth is also evidence of the origin of the nucleus.

Ossification of the vertebral bodies has been described extensively by Schmorl, and most of the following is obtained from his work. Formation of bone can be observed as early as the tenth embryonic week. Separate ossification centers appear for the bodies and for each half of the arch, at this time. At the time of birth, clefts or grooves appear in a radial fashion on the superior and inferior margins of the vertebral bodies. These increase in size for the first eight to ten years, then gradually smooth out until the twenty-first to twenty-fifth years. Strongly attached to the other elements of the intervertebral disc is the cartilaginous plate. It extends to the margins of the vertebral body, where it is intimately fused with the bony clefts and ridges. On the surface of the cartilaginous plate next to the bone, one finds the longitudinal growth of the vertebral bodies taking place. The columnar grouping of the cartilage cells, as in the long bones, can be readily seen.

The peripheral bony ring, or epiphysis, develops as follows: A small, triangular ring of cartilage surrounds the superior and inferior brims of each vertebral body. In this ring develop small foci of calcium, among girls at the age of six to eight years, among boys at the age of seven to nine years. These foci then ossify. Gradually they enlarge and fuse to form a ring,—the peripheral or marginal bony ring, or *Randleiste*. This ring is complete at the age of twelve years. At the age of fourteen or fifteen years, the peripheral bony ring gradually fuses with the vertebral body. This fusion is complete at twenty-one to twenty-five years. Fusion is slowest in the lumbar region.

Several authors [15,16] have described this ring as incomplete, because it is horseshoe-shaped and absent posteriorly. Others [10,24] have maintained that it is complete on all sides of the vertebra. While it is generally less broad posteriorly than anteriorly, it does exist as a complete ring. Any vertebra that has been freed of all soft tissue shows this ring posteriorly. Examination of eighty-eight microscopic specimens in this study has confirmed its presence posteriorly. The cartilaginous plate always ends before it reaches the posterior edge of the vertebra, abutting against a definite rim of bone (Fig. 1).

The inference made by Schmorl and Beadle is that the epiphyseal ring is a separate entity from the cartilaginous plate and serves a different function. Mau, Keyes and Compere, and Haas disagreed with this idea, believing that the two are intimately connected and serve the same function. At the end of longitudinal growth, the epiphyseal ring fuses to the vertebra, and the cartilaginous plate continues its function as part of the disc, its peripheral ends abutting on the bony rim of the epiphysis. Beadle, however, definitely stated that the epiphyseal ring is not concerned with growth. He maintained that there is no evidence of endochondral growth at the epiphysis, as there is at the base of the cartilaginous plate. He stated that the epiphysis simply grows within itself until it occupies the cartilaginous ring, then fuses to the underlying bone. Schmorl and Beadle expressed the belief that the epiphyseal ring is important only in that it serves to anchor the fibers of the annulus fibrosus firmly. They disagreed with Mau and others who claimed that wedging of the thoracic portion of the spinal column in juvenile "epiphysitis" is due to lack of growth in the epiphyseal ring. Instead, they expressed the belief that the wedging is due to herniations of the nucleus pulposus into the spongy bone of the adjacent vertebrae with resultant thinning of the disc and direct contact and compression of the anterior margins of the vertebrae. This controversial subject remains unsettled and our study does not shed any light on it one way or the other.

THE PHYSIOLOGY OF THE INTERVERTEBRAL DISC

The intervertebral disc is not a passive, vestigial remnant. It is an active, living structure, constantly functioning. The intervertebral discs serve, first, as articulations (amphiarthrosis) between the vertebrae. Without these discs the spinal column would be rigid, and could not bend to meet the delicate needs of the body. Some have called the disc a diarthrodial joint, even stating that it possesses a rudimentary joint space.[23,24] At any rate, it does serve to connect and articulate the adjacent vertebrae.

In addition to its function of articulation, the intervertebral disc acts as a shock

absorber or cushion. It transmits, modifies, and evenly distributes the force of strain. Beadle stated that the disc "is a unit whose function is to control the continual and infinitely various cross currents of tension, torsion, pressure, and mechanical shock, which interplay with one another as injurious agencies during every moment of life".

Dividing the intervertebral disc into its component parts, one sees that each of the three main structures is highly important in itself, but is dependent also on the others. The cartilaginous plate acts as a barrier between the active pressure of the nucleus pulposus and the adjacent vertebral body. Only if the cartilaginous plate is intact, will the disc act normally. If the cartilaginous plate is perforated or torn, the nucleus pulposus is allowed to flow into the adjacent vertebra, and it can no longer act as a hydrodynamic ball bearing.[6]

The nucleus pulposus is under tension in persons up to the older age groups. This tension can be simply illustrated by cutting a section through the disc and noting the bulging forth of the nucleus. The semifluid nucleus pulposus is held in restraint by the surrounding annulus fibrosus. Any movement of the spinal column is accompanied by a shift of forces in each nucleus pulposus. Flexion of the spinal column causes an anterior compression of the nucleus, with a tendency for the nucleus pulposus to be displaced posteriorly. This is the phenomenon of "nuclear retropulsion" as described by Galland. Extension of the spinal column does the opposite. A lateral shift, as in scoliosis, in turn shifts the nucleus in the opposite direction. If nuclear material is lost, as in the desiccation of old age or rupture of the nucleus pulposus, the disc no longer serves to transmit the forces of strain, and the shock is borne solely by the vertebrae, their ligaments, or their facets.

The third component of the intervertebral disc—the annulus fibrosus—is the "limiting membrane" surrounding the nucleus and serving as its capsule. The fibrocartilage of which it is composed is woven together in a complex system, with the fibers running in various directions and anchoring at strategic points, all designed to give maximal function and to accommodate for every conceivable change of force. Schmorl stressed this ability of the annulus fibrosus to accommodate itself to its surroundings. When the strength of the annulus is lost through degeneration or injury, the nucleus ruptures, usually posteriorly, presses on nerve roots, and causes pain.

The intervertebral disc can be compared to a thick rubber ball, filled with fluid, and partially compressed between two rigid discs. When the position of the discs, and the distribution of force on them change, the position of the ball changes and its shape also changes accordingly. Puncture of the ball, with escape of fluid, results in loss of tension, and the two discs are allowed to come closer together than before.

The intervertebral discs act somewhat differently in the various regions of the spinal column. There is little doubt, however, that the lower lumbar discs receive more shock and strain than any other. For this reason, this study is concerned with the fifth lumbar disc. Not only are the usual forces more active here, but there is the added shearing force as the fifth lumbar vertebra tends constantly to ride forward on the first sacral. This disc, of all the discs, is the most used and the most abused. One finds evidence here of wear and tear at an earlier age, and to a greater degree, than in any other intervertebral disc.

CONCLUSION

As a result of study of the anatomy, embryology, and physiology of the intervertebral disc, the following conclusions are drawn:

1. Vascular channels in the cartilaginous plate are normally present only in the first three decades of life.
2. There is no central "joint cavity" in the intervertebral disc.
3. No mucus was demonstrated in the intervertebral disc by De Galantha's stain.
4. The peripheral bony ring, epiphysis, or *Randleiste* is present as a complete ring, and is not absent posteriorly.

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SACRAL FRACTURES AND INJURIES TO THE CAUDA EQUINA

BY MAJOR J. GRANT BONNIN, R.A.M.C.

Recently Orthopaedic Surgeon, Emergency Medical Services, England

The association of cauda equina injuries with crush fractures of the sacrum must have been noted by many an observer, but, as far as the literature was searched, no record of any analysis of such cases could be found. It is possible that intending authors were daunted by such words as these, uttered by Kinnier Wilson: ". . . the cauda equina is too complex a structure for simplicity of syndrome, but the form all variants assume is, and must be, radicular; if otherwise, the syndrome is no longer 'pure'". The recent concentration of interest on herniation of intervertebral discs has shed new light on the problems of the lumbosacral plexus, and, at the same time, has made facts culled from the observation of injuries to the upper sacral nerve roots of greater relative interest.

Prolapse of the fifth lumbar intervertebral disc produces pressure on the first sacral nerve root primarily, but, if the prolapse is more medial or more extensive, some pressure on the second sacral nerve root may occur. The muscular and cutaneous phenomena associated with this are not sharply defined, owing to the overlap provided by pathways through other roots, but nevertheless produce a readily recognizable syndrome; in the case of the first sacral nerve root, this is characterized by weakness of the plantar flexors of the foot. This syndrome is closely parallel to that which is due to involvement of the first and second sacral nerve roots from fracture of that part of the sacrum in juxtaposition with the sacro-iliac joint. Further observation of this latter syndrome should extend our knowledge of the effects of pressure on the second sacral nerve root.

ANATOMY

The long auricula-shaped facet of the sacro-iliac articulation extends from the level of the upper margin of the first sacral foramen to the upper margin of the third. The first and second anterior and posterior sacral foramina thus weaken considerably that part of the bone connecting the lateral mass of the sacrum with the body of the bone, and provide the most readily broken link in the solid connections between the ilium and the vertebral column. From this weak spot, fractures of the sacrum caused by indirect violence are prone to start and spread; and it follows that any fracture of the sacrum caused by violence transmitted through the sacro-iliac joints affects this area to a greater degree than elsewhere. This tends to involve predominantly the first and second sacral nerve roots, while the lumbosacral trunk above and the third sacral nerve root below may be involved to a lesser degree.

MODE OF SACRAL FRACTURE

Fracture of the sacrum is most common in association with fracture of the innominate bone, a sufficient clue to its most common method of production. The bone is strongly resistant to compression; and, in the intact pelvis, excluding direct violence, it can be acted upon only by compression force. The more common sacral and pelvic injuries are secondary to violence applied to one leg or to one side of the body. Consideration of the mechanics of the bone, as well as of the common type of violence, thus suggests that the sacrum is broken by tension and shear, forces to which all bones offer least resistance. The idea that this violence is transmitted through the innominate bone is in conformity with the ideas recently expressed by Taylor on the violence causing dislocations of the innominate bone. Fracture through the weak area of the bone may occur in three ways, or four, if pure compression is given its unimportant place.

1. *By rotation:* The injury is severe with separation of the pubic symphysis, or fracture of the ischiopubic rami. The force is one of hyperextension, acting on the lower extremity, and rotates the affected innominate bone around the horizontal axis of the sacro-iliac joint, so that the pubis is depressed. If the sacro-iliac joints do not yield (and to rotation they offer their greatest resistance), fracture through the first and second sacral foramina occurs. The fact that this rotation takes place is frequently shown by elevation of the posterior superior iliac spine, without elevation of the innominate bone concerned. Rotation of the innominate bone in the opposite direction is less common, and is indicated by elevation of one side of the pubic symphysis.

2. *By leverage:* Once the pelvic ring has been broken anteriorly, its two halves may be widely separated. The force responsible may be considerable, as in "run-over" accidents, or when transmitted through the abducted limb. Once the sacro-iliac joint has been opened to its maximum, there is a tendency for fracture to occur through the buttresses of bone between the first and second sacral foramina, as a fully opened hinge tends to tear out by the screws. Less commonly, this action is reversed, and the pubic symphysis is made to overlap by compression.

3. *By shear:* One half of the pelvis may be driven almost directly backward by impact against the knee, when the patient is in the sitting position. More commonly this produces posterior dislocation of the hip; but, if the hip is slightly abducted, one half of the pelvis may be pushed up and back. Under these conditions, the lateral mass of the sacrum is submitted to a shearing stress, under which it is most likely to fracture.

As a general rule, no accurate analysis of these forces is possible in the individual case, in which they are combined in a greater or lesser proportion. The high incidence of sacral fracture in association with fractures of the pelvic ring is thus accounted for, although statistics of this vary widely; thus Wakeley gives 4 per cent. as the figure, while Furey gives 74 per cent. The frequency with which sacral fractures will be seen depends chiefly upon the quality of the roentgenogram and the industry with which they are sought, for postmortem examination shows small chip fractures at the margin of the sacro-iliac joint in almost every case of fracture of the pelvis. These are frequently invisible in the roentgenogram, because of the density of superimposed bone shadows. What we are interested in is the percentage of fractures of the sacrum visible in roentgenograms of reasonable quality, and the author's experience (Table I) confirms that of Mendelmann in giving a figure of 45 per cent. as approximately correct.

ROENTGENOGRAPHIC EXAMINATION

Satisfactory definition of the sacrum does not occur in the average roentgenogram taken for fracture of the pelvis, owing to the curvature and obliquity of the bone. As these two factors cannot be entirely overcome, a foreshortened view is always seen, in which the first and second anterior sacral foramina are very close to one another. The thin compact bone above each foramen is tilted edge on, and thus shows up in the roentgenogram as a fine line arching above each foramen. In many roentgenograms, this line above the second foramen appears as the continuation of the brim of the pelvis (Fig. 1, *G*). Above this is the curved line over the first sacral foramen, merging with the shadow of the lip of the first sacral body; while below, the third and fourth sacral foramina are more distinct. The posterior sacral foramina are obscured, and are recognizable only as an area of decreased density on either side of the mid-line. The weakest area of the sacrum is recognizable as running from the notch between the articular process for the fifth lumbar vertebra and the lateral mass of the sacrum above (Fig. 1, *C*), through the first and second foramina to emerge below at the edge of the sacrum, usually through the third sacral foramen.

In most views of the sacrum, two promontories are visible on the shadow of its lateral edge. The first represents the junction of the sloping upper surface of the bone with the most anterior portion of the auricular facet, and so lies just below the upper level of the

TABLE I

CLASSIFICATION OF FORTY-FOUR FRACTURES OF THE PELVIC RING *

Posterior Disruption	Anterior Disruption			
	Fractures of the Ischiopubic Rami on one side	Fractures of the Ischiopubic Rami on both sides	Separation of the Pubic Symphysis	Totals
No posterior lesions seen	6	4		10
Sacro-iliac dislocation				
Unilateral	2	1 (with sacral fracture)	2	5
Bilateral		1	2	3
Fracture of the ilium lateral to the sacro-iliac joint	2 (1 with sacral fracture)	1		3
Fracture of the ilium running into the sacro-iliac joint	3 (1 with sacral fracture)	4 (2 with sacral fracture)		7
Central dislocation of the femur	1			1
Fracture of the sacrum only	5	7	1	13
Fracture of the sacrum on one side, and of the ilium running into the sacro-iliac joint on the other		2		2
Totals	19	20	5	44

* This table shows the high incidence of sacral fractures associated with other fractures of the pelvis,—twenty sacral fractures, or 45 per cent.

The etiological classification of sacral fractures is as follows:

1. *By Direct Injury*
   a. Complex comminuted fractures from missiles;
   b. Transverse fractures below the level of the sacro-iliac joint;
   c. Compression fractures of the posterior arch.
2. *By Indirect Injury*

As illustrated by the twenty cases of sacral fracture listed in Table I and classified in Table II.

TABLE II

ANALYSIS OF SACRAL FRACTURES

Type of Fracture	Main Fracture	Associated Fractures *
a. Juxta-iliac marginal fractures	5	6
b. Fractures through the first and second sacral foramina, with upward displacement of the lateral sacral mass	5	
c. Compressed and comminuted fractures of the same region, with loss of sacral pattern	4	
d. Fissure fractures separating the lateral mass through the first, second, third, and fourth sacral foramina, with little or no displacement	6	
e. Ligament-traction fractures at the attachment of the sacrotuberous ligament		3
f. Transverse fractures at the level of the third sacral foramina (caused possibly by direct violence, or possibly by ligament traction)		2
Totals	20	11

* These were small fractures of the sacrum associated with the twenty main fractures; but, as they occurred in the same cases, they cannot be added to the twenty fractures in individual cases.

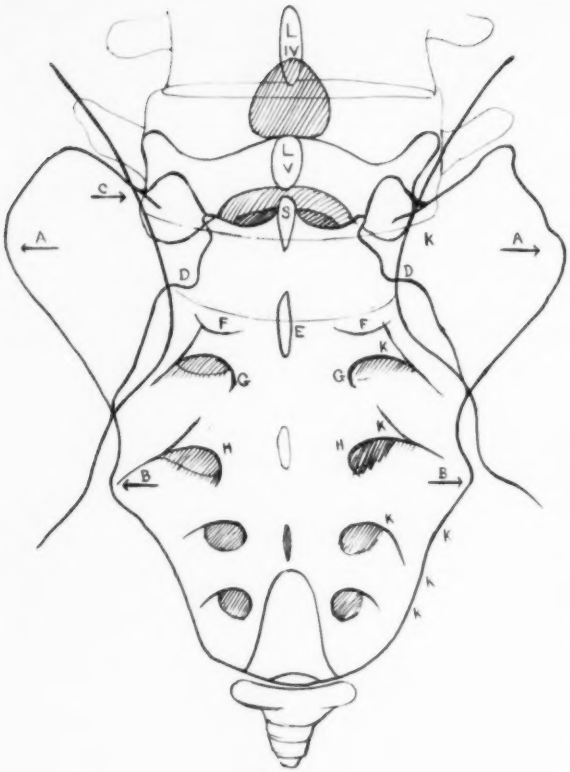

FIG. 1

FIG. 1

Diagram of the shadows cast by an average anteroposterior roentgenogram of the sacrum.

A-A: Line of the upper lateral sacral promontories.
B-B: Line of the lower sacral promontories.
C: Notch between the lateral mass and the articular facets for the fifth lumbar vertebra.
D: Notch representing the first posterior sacral foramen.
E: Shadow of sacral promontory.
F: First anterior sacral foramina.
G: Second anterior sacral foramina.
H: Third anterior sacral foramina.
K-K: Sites where fractures are common and readily found.

sacro-iliac joint, and the second and lesser promontory, which is missing in some views, lies opposite the brim of the pelvis and represents the lower border of the sacro-iliac joint. These points serve as convenient landmarks in true anteroposterior views of the bone, for comparative measurement with the opposite half (Fig. 1, *A-A* and *B-B*). In many crush fractures, these promontories will be found nearer to the mid-line than are those of the unaffected side. When this is of significance, it is usually apparent to the naked eye; minor degrees of change are easily produced by rotation of the pelvis and have to be discounted. As has been pointed out,[1] the value of the obstetric view of the pelvis in the determination of the displacement following pelvic fractures must not be forgotten. The usual change is an alteration in the outline of the brim of the pelvis, showing itself as an increased angulation through the line of the anterior sacral foramina, caused by the forward displacement or impaction of the lateral mass of the sacrum on the main mass of the bone (Fig. 2).

The recognition of sacral fracture is most readily accomplished by inspecting the continuity and regularity of the arches above the anterior sacral foramina, and comparing them with the opposite side. The inspection of the lumbosacral notch above (Fig. 1, *C*) may also provide information; the eye should then travel to the free border of the sacrum lower down. Fractures frequently come to view here, in the vicinity of the third sacral foramen. A linear fracture of the ligament-traction type may be apparent at the edge of the bone, corresponding to the attachment of the sacrotuberous ligament, and, if so, provides additional evidence of the movement of one half of the pelvis. This fracture was apparent from the beginning in one of the five cases reported here, but in another it became apparent only after a period of seven weeks had elapsed (Fig. 6-B). During this time, new-bone formation at the base of the detached ligament made the separation obvious, and substantially duplicated the picture seen in the first case (See Table II).

NEUROLOGICAL FEATURES

The syndrome arising from pressure on the first and second sacral nerve roots shares the vagueness of similar syndromes elsewhere, and yet forms a combination of sensory and motor changes which is readily recognizable. That such would be the case can be deduced from a consideration of the distribution of the nerve fibers in the plexus, and the fact that the damage in most cases is incomplete. The anterior sacral foramina are at least twice

the diameter of the issuing nerve roots, which would seem to make bone pressure unlikely, unless the displacement is considerable. Injury may, however, be produced by stretching, by the pressure of small fragments of bone, by surrounding hemorrhage, and probably by the contraction of fibrous tissue and callus. The onset of symptoms may thus be delayed, and few signs may be elicited at the time of the first examination, while more marked features may appear in the recovery period. Two of the reported cases show this feature (Cases 4 and 5).

The most characteristic feature of the syndrome is the distribution of the muscle paresis, which is caused by pressure or division of the first or second sacral nerves. If either or both are completely divided, obviously a rare phenomenon, the following muscles would be affected, according to various authors: [2]

Muscles Affected	Authority
Pyriformis *	Dejerine, Gray, Grinker, Monrad-Krohn
Gastrocnemius *	Dejerine, Gray, Grinker, Monrad-Krohn, Purves-Stewart, and Wechsler
Soleus *	Dejerine, Gray, Grinker, Monrad-Krohn, Purves-Stewart, and Wechsler
Glutei,—maximus, medius, and minimus †	Dejerine, Gray, Grinker, Monrad-Krohn, Purves-Stewart, and Wechsler
Semimembranosus	Dejerine, Gray, Grinker, Monrad-Krohn, Purves-Stewart, and Wechsler
Biceps femoris	Dejerine, Gray, Grinker, Monrad-Krohn, Purves-Stewart, and Wechsler
Flexor digitorum longus	Dejerine, Gray, Grinker, Monrad-Krohn, and Purves-Stewart
Tibialis posterior	Dejerine, Gray, Grinker, Monrad-Krohn, and Purves-Stewart
Intrinsic muscles of the foot *	Spalteholz and Berry
Plantaris *	Spalteholz and Berry

* Almost completely paralyzed.
† Grinker, Monrad-Krohn, and Wechsler believe that the glutei are not affected if only the second sacral is involved.

The peroneal and anterior tibial compartments are very slightly affected. Broadly speaking, we thus expect to find marked weakness of plantar flexion at the ankle, with loss of the ankle jerk, and loss of power in the hamstrings and in the glutei. Paresis of the three posterior groups of muscles of the lower extremity (calf, hamstrings, and buttock) thus characterizes the lesion; in addition, the severity of the paresis is selective, the calf being more markedly paralyzed than any other group. The segments which supply the biceps femoris seem to vary in the individual, but are most commonly given as the fifth lumbar, the first, second, and third sacral. Our observations would suggest that the first and second sacral are chiefly concerned; as, in two reported cases, the muscle was almost completely paralyzed, and in only one of these was damage to the fifth lumbar and third sacral roots likely. Marked paralysis of the biceps femoris was noted in all cases, and is probably a distinctive mark of the syndrome.

The ankle jerk will be lost, if there is serious damage to the first sacral nerve root; and its loss is a common feature of the syndrome. In less severe injuries, the reflex is diminished. The calf muscles and the hamstrings are always tender to the touch, and fibrillation may be seen.

SENSORY CHANGES

The sensory changes found occurred within the areas of the dermatomes assigned to the first and second sacral nerves. Although there is still no definite agreement among authorities as to the limits of the dermatomes, their locations have been roughly determined.[7] These are to be compared with the affected areas in Cases 3 and 4. Broadly speaking, alterations in sensation, paraesthesia, and referred pain are to be expected on the

outside of the calf and the lateral half of the foot. The changes we have noted are the same as those of nerve compression from any other cause. Thus immediate severe pain referred to the back of the leg and outer side of the foot was found. The patient complained of numbness and tingling in the area; and clinical examination demonstrated loss of sensation to light touch and disturbed sensation to pinprick. In view of the sensory overlap and the fact that lesions are most often incomplete, areas of complete loss of sensation are unlikely, except in very severe lesions. This incompleteness is frequently shown by the appearance of hyperaesthesia, either occurring in an isolated area (Case 4) or surrounding an area of otherwise altered sensation (Case 3). The sensory findings thus share the same qualities as those from the pressure of a herniated nucleus pulposus, but tend to affect the two roots—first and second sacral—together, in contrast to the single root involved in a disc lesion. Pain, however, is in marked contrast. While there is usually pain at the infliction of the injury, it rapidly subsides; and the patient is free from pain of a "nerve" type, although he may have aching as a result of the injury. It would appear that this is due to the fact that, in a herniated nucleus pulposus, the pain arises from tension on the nerve, which is intact. In the syndrome of the sacral fracture, the nerve is apparently completely or partly divided, and, after the infliction of the injury, is painless.

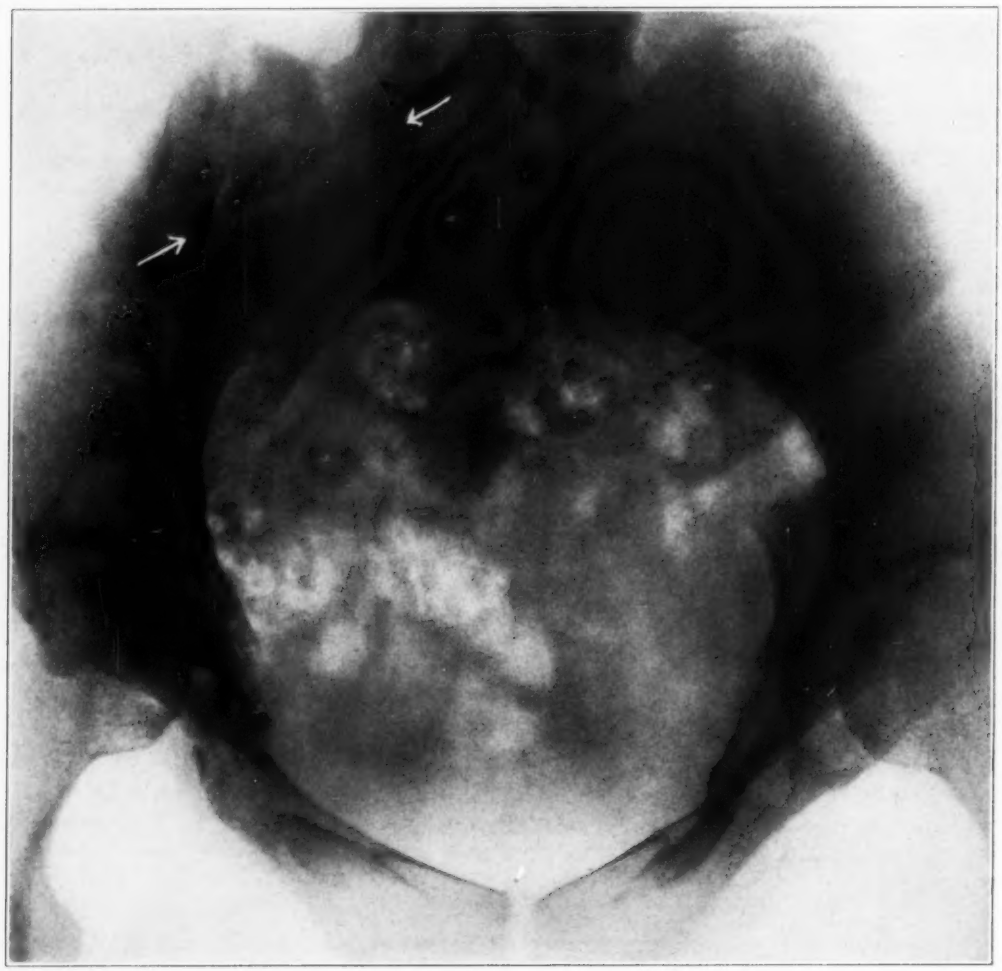

FIG. 2

Obstetrical view of the pelvis, showing the characteristic forward displacement of the lateral mass of the sacrum; the fracture obviously runs through the sacral foramina. Arrows indicate secondary fracture of the lateral mass.

Unless the remaining fibers are stretched or stimulated by some other method, there is no complaint of pain. A positive Lasègue sign in the early stages is often of doubtful significance, because of the extensive local damage, but it may become suggestively positive as the patient recovers. The nerves of the bladder and bowel issue below the second sacral nerve root, and, since the sacral fracture is unilateral, disturbance is not to be expected. A temporary upset of bladder and bowel function is, however, not uncommon. In the case of the bladder, it may arise from bruising in the neighborhood of the trigone or of the urethra. A ruptured urethra may be associated with the condition. Similarly, the rectum may be disturbed from hemorrhage into the pelvirectal fascia or the root of the sigmoid mesocolon, which may result in faecal impaction, while the immediate complete recumbency and lack of activity encourage constipation. Vasomotor and trophic changes are not found.

TREATMENT

The sacrum can be influenced only through that half of the pelvis attached to the fractured portion. Every endeavor must be made to reduce the pelvis satisfactorily by the use of the appropriate method. A sling, counterbalancing the patient's weight, together with traction on the lower end of the femur, will generally be found the most efficacious. Once the pelvic displacement is reduced, the sacrum must be left to itself. In some cases—for example, those with only minor compression of the sacrum—no pelvic reduction is necessary; such patients should be treated as soon as possible by active exercises in bed, and by such physiotherapeutic aids as may facilitate the active use of the muscles. In no case is the muscle paralysis so complete that deformities will arise if the patient is given exercises. Where paralysis exists, its incomplete nature is suitably dealt with by exercises against graduated resistance, together with a little radiant heat and massage. As soon as the pelvis is consolidated, usually at the end of eight weeks, walking is encouraged.

PROGNOSIS

In the lesser degrees of injury, the prognosis is good, complete recovery occurring at the end of a year; although there may be weakness in the leg and some slight permanent muscle wasting. In the severe cases, the prognosis is not good. Complete recovery of the power in the calf does not occur, and the limb is permanently weaker than its fellow. The ankle jerk may remain absent or diminished. Combined with this is frequently some elevation of the affected half of the pelvis, with consequent shortening of the lower extremity and a limp. Because of the paresis of the glutei, there may be dropping of the pelvis, when weight is taken on the affected limb. The hamstrings, although wasted, cause little disability. With the lapse of time, the limp may be disguised, but permanent partial disability is inevitable.

CASE REPORTS

Case 1. L. C. D., aged twenty-six years, was admitted to an E. M. S. Hospital on December 9, 1941. He had been sitting in a seat running along the side of an Army lorry, when it was struck by another vehicle. He had been thrown violently among his companions on the opposite side. He lost consciousness and was brought to the Hospital in mild shock, with abrasions of the face and right knee, and bruising and tenderness over the sacrum. On December 11, the patient complained of pain in the left lower extremity. On December 18, a distended bladder necessitated catheterization. This condition appears to have been a transitory disturbance, as the patient passed urine normally on admission, and there is no note of subsequent difficulty. Constipation required the use of enemata. On January 21, 1942, the patient was transferred to a fracture clinic.

Investigation showed a double pelvic fracture anteriorly through the ischiopubic rami, and another fracture through the sacrum close to the sacro-iliac joint, with elevation of the lateral mass of the sacrum (Fig. 3). The whole left half of the pelvis was raised half an inch. The left sacro-iliac joint appeared widened, but the surfaces were otherwise not displaced. He had no pain, and complained only of weakness

in the left limb. Examination showed disuse atrophy of both limbs, but, on the left, there was more obvious wasting of the calf, some wasting of the biceps femoris, and loss of tone in the glutei. The left lower limb showed three-quarters of an inch of shortening. Full exercises in bed were given, with a marked improvement in the muscle tone of both lower extremities, but with an equally marked failure of the calf on the left side to respond. On February 2, when the patient was allowed to walk for the first time, there was half an inch of wasting of the calf, and the patient could not stand on the toes of that leg.

The disability slowly improved, so that the patient was capable of moderate activity; but the weakness of the calf, diminished ankle jerk, and some loss of the bulk of the glutei remained, when he was sent to a convalescent institution on April 18, 1942. He was returned to the Army, but only for sedentary duties.

Case 2. A. B. was sitting alongside the man described in the first case report. He was unable to move after the accident, and had severe pain in the left lower extremity. He was admitted to the Hospital in mild shock, with hematuria which cleared up in two days. There was no difficulty with micturition. Pain diminished rapidly with rest in bed, but there was some constipation for the first three weeks after injury. He was transferred to a fracture clinic on January 24, 1942, seven weeks after his injury.

On examination, the patient was found to be of asthenic build, and the lower extremities particularly were wasted. There was an ulcer, two and a half by three inches, over the posterior superior iliac spine on the left. This appeared to be due to the breakdown of a hematoma. Roentgenograms showed a quadruple fracture of the pelvis, both sacro-iliac joints were widened, and there were fractures of the ischiopubic rami on both sides (Fig. 4-A). The left side of the sacrum was crushed, fissures running from the notch above, through the first and second foramina, and emerging at the margin of the sacrum just below the left sacro-iliac joint, while a small fissure ran into the third and fourth sacral foramina. On the right, a fragment of bone, corresponding to most of the area of attachment of the sacrotuberous ligament to the free border of the sacrum, was separated by a linear fracture (Fig. 4-B). Both limbs showed marked disuse atrophy, but the left was much weaker and more wasted, and there was an almost complete loss of power in the extensors of the ankle and absence of the ankle jerk. On February 3, there was still half an inch of wasting of the calf, and a small patch of anaesthesia over the left buttock, just below the iliac crest. No disturbance of sensation could be found in the thigh, leg, or foot. Roentgenographic examination showed that the whole innominate bone on the left side was swung forward, so that the posterior superior iliac spine was excessively prominent. Two fissures were present in the ala of the right ilium.

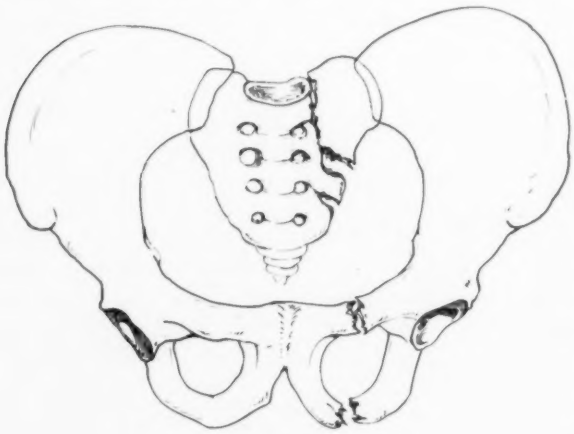

Fig. 3

Case 1. Line drawing of the pelvic and sacral fractures.

Slow progress was made with active exercises, and on March 8 the patient was allowed up, but he found difficulty in walking because of the loss of balance on the left limb. There was still half an inch of wasting of the calf and diminished ankle jerk. The patient gradually walked better; he had a pronounced limp, which was due in part to shortening, but chiefly to loss of muscle power in the glutei, a markedly wasted calf, and some loss of power in the hamstrings; the wasting of the biceps femoris was particularly marked. He was discharged from the Army on May 28, 1942.

Case 3. A. C. On March 28, 1942, the patient, aged thirty-two years, had been sitting on the side seat in a lorry, when it swerved to avoid another lorry. He was thrown out, and rendered unconscious for a short period. Taken to a nearby hospital, he was treated for shock, and a scalp wound was sutured. The diagnosis of a ruptured kidney was made, as he had hematuria which lasted for fourteen days. There was no difficulty with micturition. Roentgenograms showed a fracture of the inferior ischiopubic ramus in the usual location, and a fracture of the superior ischiopubic ramus close to the acetabulum. The fragments were elevated and overlapped (Fig. 5-A). A gross fracture of the sacrum was present, with destruction of the sacral pattern around the first, second, and third sacral foramina. A fissure, starting from the notch above on the left, ran through these foramina, and allowed elevation of the corresponding portion of the lateral mass of the sacrum, leaving a wide defect below in the lateral border opposite the third sacral foramen (Fig. 5-B). The patient complained of severe pain in the left lower extremity and foot; this was aggravated by certain movements, and partially relieved by flexion of the knee. There was numbness over the sacrum, the lateral side of the foot, and the back of the calf. The severe pain slowly diminished, and the area of numbness decreased. Three months later he was transferred to a fracture clinic.

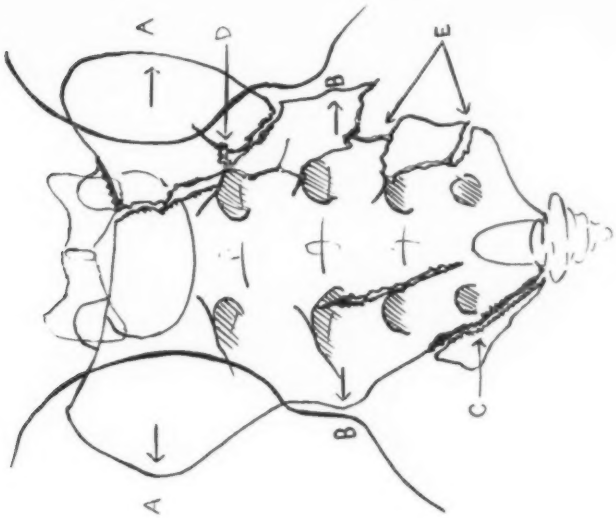

FIG. 4-B

Line drawing of the sacral fractures.
A-A and *B-B:* Note the approximation of the promontories on the left to the mid-line.
C: Fracture of the sacral margin caused by the pull of the sacrotuberous and sacrospinous ligaments.
D: Marked loss of sacral pattern.
E: Fissures running from the anterior sacral foramina to the lateral margin of the sacrum.

FIG. 4-A

Case 2. Note the fractures,—ilium, ischium, and pubis on the right, and sacrum, ischium, and pubis on the left.

FIG. 5-A

Case 3. Note the gross destruction of the sacral pattern, and the elevation of the lateral mass of the sacrum.

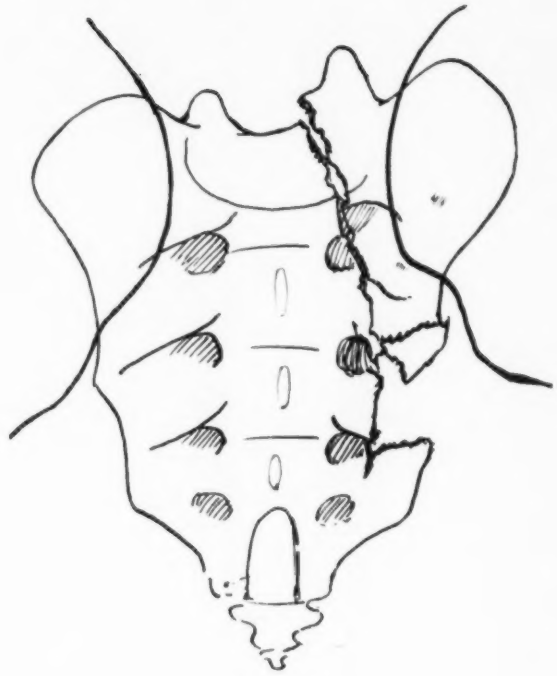

FIG. 5-B

Line drawing of the sacral fracture, showing the involvement of the left articular facet for the fifth lumbar vertebra, allowing partial spondylolisthesis.

On June 27, 1942, he was still complaining of pain in the left limb and groin and over the sacro-iliac region. Paraesthesia was now confined to the outer border of the left foot. There was wasting of the left buttock, the hamstrings, particularly the biceps femoris, in which fibrillation could be seen, and the calf. The calf was tender, and was half an inch less in circumference than the right, and there was one and a half inches of wasting in the thigh. The left lower extremity was half an inch shorter than the right, and there was a positive Trendelenburg sign. The left ankle jerk was absent. Sensory examination showed a loss of sensation to light touch and pinprick over a small area on the medial aspect of the left buttock, with a surrounding area of hyperalgesia and loss of sensation to light touch (Fig. 5-C). There was loss of sensation to light touch and blunting of sensation to pinprick over the back of the lower half of the left leg, the outer side of the foot, and part of the sole (Fig. 5-D). Fresh roentgenograms showed the presence of the fractures described, but also showed some degree of spondylolisthesis. It was considered that this was a true traumatic lesion, caused by fracture and displacement of the sacral facet of the fifth lumbar vertebra on the left. Investigation of the foot showed a loss of response to faradism of all the small muscles, with the exception of the abductor hallucis and the first interosseous. The area in which sensation to pinprick was blunted decreased slowly, until, in the fifth month, it was confined to the outer side of the fifth metatarsal, all of the fifth and half the fourth toes. Pain, of an aching character and related to activity, persisted over the lumbosacral region posteriorly, and was considered to be caused by the spondylolisthesis. The patient walked with a limp, had a positive Trendelenburg sign, and was unable to raise himself on the toes of the left foot.

At the end of the seventh month, the power in the affected limb had increased, the patient could balance on the limb, but could not raise himself on his toes. The biceps femoris was still extremely weak and wasted; the ankle jerk was absent; and the calf was still wasted. There was a return of faradic response in the small muscles of the foot. Blunting of sensation to pinprick was still present over a small area on the left buttock, while the area over the fifth toe showed hyperaesthesia only. In October 1942, he was discharged from Army.

Case 4. G. P. On February 5, 1942, this patient, aged twenty-four years, had been driving a lorry which had skidded and overturned; he had been thrown heavily against the outer side of the right hip. He sustained a sharply defined bruise over the right greater trochanter, which suggested that he had struck some narrow object. On admission, he was in mild shock, and slight hemorrhage from the urethra was noted. There was some mid-line suprapubic tenderness. A catheter was passed and blood-stained urine was first withdrawn; the urine later became clear. No evidence of perineal bruising appeared, and the catheter was withdrawn the next day; the patient subsequently passed urine normally. Examination of the right lower extremity showed no signs of neurological disturbance. Roentgenograms revealed a fracture of the tip of the greater trochanter (obviously caused by direct violence), the separation of a small flake of bone on the

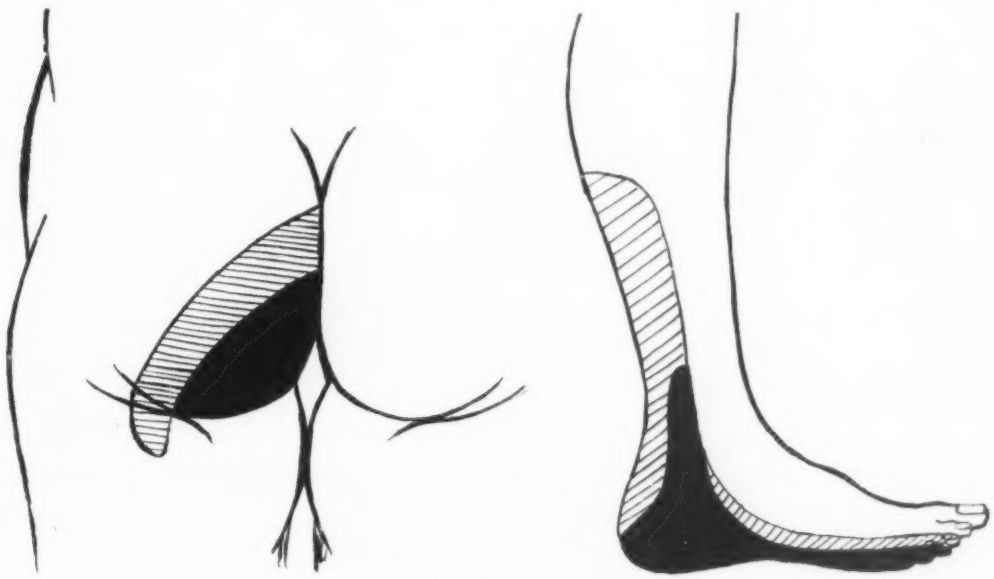

Fig. 5-C Areas of sensory loss. Fig. 5-D

Fig. 5-C: Black: The area of loss of sensation to light touch and pinprick on the left buttock.
Shaded: The surrounding zone of hyperalgesia.

Fig. 5-D: Shaded: The area of loss of sensation to light touch and blunting of sensation to pinprick on the outer surface of the foot at the end of the third month.
Black: The area of similar loss at the end of the seventh month. At the end of the year, the little toe and metatarsal area only were affected.

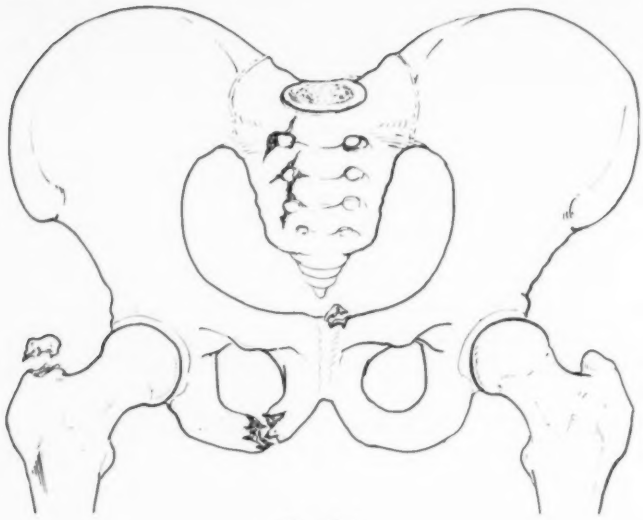

FIG. 6-A

Case 4. Showing fractures of the tip of the greater trochanter and the inferior ischiopubic ramus on the right, and the separation of a small flake of bone on the left side of the symphysis pubis.

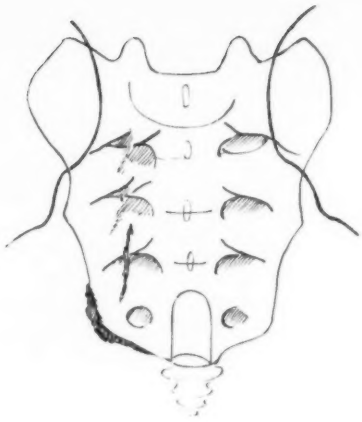

FIG. 6-B

Showing the fractures of the sacrum in detail. The appearance of the sacrum is normal in spite of multiple fissures. The cross-hatched area represents the site of new-bone formation, seen in the seventh week.

left side of the pubic symphysis (probably related to the urethral bruising), and a fracture of the inferior ischiopubic ramus on the right side, with little displacement. A crush fracture of the right side of the sacrum was indicated by loss of the sacral pattern, and by a fissure running down and out toward the outer margin of the sacrum (Fig. 6-A).

Satisfactory progress was noted until the fourteenth day, when the patient complained of shooting pains in the right limb; some loss of power in the calf, which had been suspected, became obvious; the whole of the right lower extremity was generally weaker than the left. Treatment by active exercise in bed was continued, and by the fifth week the pain had become localized to the anterior half of the sole of the right foot, which was hyperaesthetic to touch (Fig. 6-C). Wasting of the right leg continued, and in the eighth week the circumference of the calf was three-eighths of an inch less than of the left. At this period, he was allowed up, and was able to walk reasonably well, having only a slight limp due to pain. There was no shortening of the right lower extremity, and the hamstrings and glutei, although slightly reduced in bulk, could carry out normal functions. By the tenth week, the hyperaesthesia in the sole of the foot had been reduced in intensity, and the patient walked with a barely detectable limp, although there was still half an inch of wasting in the thigh and one-quarter of an inch of wasting in the calf.

Roentgenographic examination in the seventh week, prior to his getting up, showed new-bone formation along the right lower border of the sacrum, corresponding to the attachment of the sacrotuberous ligament (Fig. 6-B), producing a picture resembling that seen in (Case 2, Fig. 4-B).

On October 12, 1942, three months after admission, he was transferred to a convalescent depot for regrading.

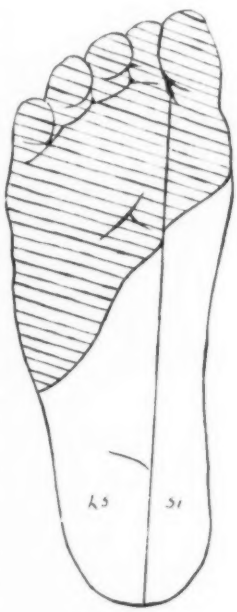

FIG. 6-C

The shaded portion shows the area of hyperaesthesia to touch. The dermatomes for the fifth lumbar and the first sacral nerve roots are indicated.

CASE 5. M. T., aged twenty-six, a guardsman of powerful build, was admitted to the Hospital, unconscious after a motorcycle accident, on June 16, 1943. No evidence of injury to the skull was found, and the patient regained consciousness in six hours. He was in moderate shock. An abrasion over the chin and pain over the mandibular joints suggested that he had been knocked out by a blow on the jaw. He complained of pain in the right knee and the right side of the pelvis. An abrasion was present below the right knee, and the knee was distended with fluid and was difficult to examine because of pain and muscle spasm. Tenderness was present over the right sacro-iliac joint, and there was pain on compressing the pelvis; the patient found it impossible to turn in bed. There was no urinary disturbance. Roentgenographic examination of the knee joint was negative. The pelvis, however, showed a triple fracture (Fig. 7-A). The ischiopubic rami on both sides were fractured, and there was a loss of sacral pattern

over the right side of the sacrum, with slight narrowing of that half of the bone. There was no upward dislocation of the innominate bone. The patient was, therefore, kept flat in a fracture bed, with a balanced pelvic sling to assist in raising him. As soon as pain would permit, that is, four days after admission, a complete neurological examination was made. No sensory disturbance was found, but there was loss of the right ankle jerk. The hemarthrosis in the right knee, later on clinical examination, was found to be due to a rupture of the cruciate ligaments. Reflex wasting of the quadriceps, in spite of treatment, was, therefore, to be expected,—this exaggerated still further the appearance of wasting of the limb due to sacral-root injury.

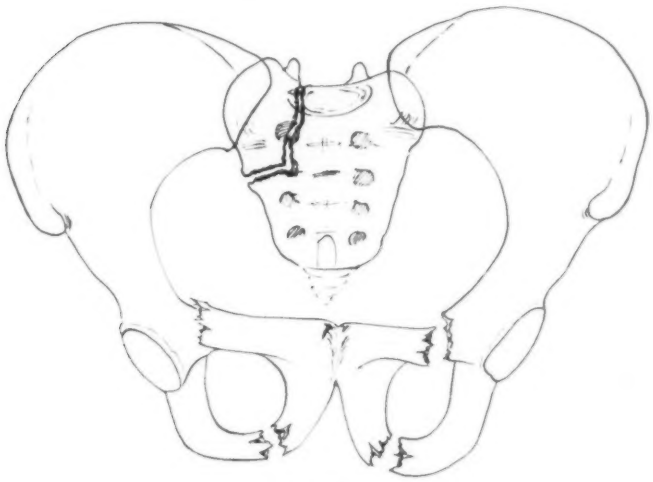

FIG. 7-A

Case 5. Line drawing of the pelvic fractures.

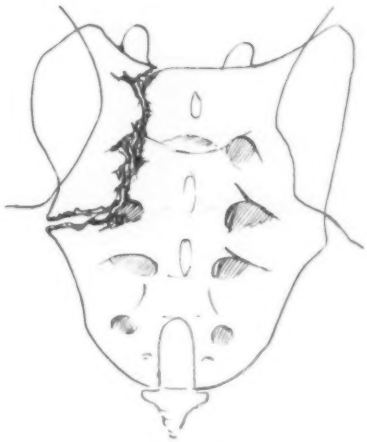

FIG. 7-B

Tracing from the roentgenogram, showing the sacral fractures in more detail.

On July 1, 1943, two weeks after injury, wasting of the right calf and muscle tenderness became marked, and continued to progress. There was complaint of numbness and tingling in the outer three toes, and a vague alteration of sensation like "sitting on a wet cloth" over the right buttock. On July 15, all the three posterior groups of muscles of the leg were wasted and tender to the touch. The ankle jerk was still absent. The weakness of the calf and the hamstrings was disproportionate to the degree of wasting, and was very marked. The biceps femoris was weak, but its contraction was visible. The muscles of the anterior compartment of the leg, the peronei, and the small muscles of the foot were normal to clinical examination and to electrical stimulation. There was a patch of altered sensation, about eight inches in length, over the popliteal space, and a similar patch over the right buttock. There was loss of sensation to pinprick in the center of these areas, and to light touch on the outside. The areas of altered sensation slowly decreased in size, until, in the eighth week, only a vague alteration to light touch remained. The wasting of the muscles, however, persisted, and the ankle jerk was still absent. At the end of the ninth week, as soon as he was free from pain, the patient, who had had exercises daily in bed, was allowed up. Movements of the right knee were full, but there was still marked wasting of the quadriceps and relaxation of the cruciate ligaments. The patient walked with a bad limp, which has steadily improved.

On September 10, 1943, the patient was sent to a convalescent depot, with a recommendation for regrading to a lower medical category. There was still wasting of the posterior groups of muscles of the leg; the ankle jerk was absent; and there was a slight limp. The patient has subsequently returned to sedentary duties.

COMMENT

Of the five cases, the third was the most severe, the patient's condition probably representing an almost complete division of the first and second sacral nerve roots. The clinical picture in this case corresponds to that which, on theoretical grounds, would be expected from complete division. The injury is more extensive than the lesion produced by division of the first sacral nerve, but includes its characteristic features.

Case 4, although less severe than the others, is interesting in showing the possibility of late onset of symptoms when there is little sacral displacement. This is probably due in part to the fact that partial paralysis of a muscle, if mild, is readily overlooked. In this case, although paralysis was suspected, because of the disproportionate loss of power

compared with the muscle bulk, definite diagnosis was not possible until muscle atrophy had made the wasting of the calf obvious. At the same time, damage to the plexus was confirmed by the occurrence of referred pain and paraesthesia in the foot.

In the first and second cases, sensory changes, which may have been present, were not recorded when the patients were first seen at other hospitals. These cases point a moral. The wasting present in both legs was attributed to disuse atrophy and no comparison of the limbs was made. Once this was done, it was obvious that there was a considerably greater loss of muscle in one leg, with paresis of specific muscle groups, and this could be readily confirmed with a tape measure. In Case 2, it is remarkable that such severe damage should have affected chiefly the motor nerves. There was only a small area of anaesthesia on the opposite buttock, probably due to superficial nerve injury. Pain, however, was marked in the early stages of the injury. Sensory changes may have cleared up before the end of the seventh week, although it is more probable that the lack of sensory change found at that time (which was present at the outset in all other cases) is due to a greater overlap of sensory disturbance than of corresponding root motor enervation.

In three of the cases, gross sacral damage was associated with severe pelvic fractures and obvious displacement. In the fourth case, the displacement was not obvious. The subsequent formation of new bone around the attachment of the sacrotuberous ligament suggested that the displacement may have been greater at the time of injury than the first roentgenogram showed, a feature probably common to all cases. The second case is interesting in drawing attention to fracture of the sacral margin by the pull of the sacrotuberous ligaments; this mechanism is confirmed by the changes noted in the fourth case.

In the fifth case, the mechanism of pelvic and sacral fracture is shown, by the site of the abrasion and damage to the cruciate ligaments, to be due to a violent blow just below the flexed knee. Such an injury is not uncommon to a motorcyclist in a collision. The slow appearance of the full and characteristic syndrome is typical, as is the disproportionate muscle wasting compared with sensory loss.

SUMMARY

The frequency of roentgenographically obvious fractures of the sacrum in association with fractures of the pelvic ring was 45 per cent. in this series of cases.

The varieties and mechanism of sacral fractures are discussed; most of these fractures are caused by leverage through the detached half of the pelvis.

The involvement of the sacrum in this type of fracture is localized around the first and second anterior and posterior foramina.

The roentgenographic features characteristic of this lesion are described.

Disturbance of the first and second sacral nerve roots produces a readily recognizable syndrome. This syndrome is characterized by sensory disturbances over the outer side of the foot, weakness of the hamstrings and glutei, marked weakness of the calf, and diminution or loss of the ankle jerk.

Recovery is slow, and permanent impairment of gait and limitation of activity may follow.

The author wishes to record his indebtedness to Dr. R. Arden Jones for assistance with the neurological examination of the patients and criticism of the article, and to Dr. F. R. Berridge for comments and advice on the roentgenography.

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THE FIXATION OF FRACTURES OF THE UPPER FEMUR AND HIP WITH THREADED, HEXAGON-HEADED, STAINLESS-STEEL SCREWS OF FIXED LENGTH*

BY PAUL H. HARMON, PH.D., M.D., SAYRE, PENNSYLVANIA

From the Section on Orthopaedic and Traumatic Surgery, the Guthrie Clinic and Robert Packer Hospital, Sayre

During the past four years, we have employed long, slender, threaded, stainless-steel screws of definite length, capped with a hexagonal head of the same material, for the fixation of fractures in the upper femur, including those in the region of the hip. The results obtained seem to justify a description of the method of treatment employed and of the construction of the screws.

CONSTRUCTION OF THE SCREWS

Figure 1-A shows the screws. They are prepared in several fixed lengths, those most frequently used being three, three and one-half, and four inches in length. These lengths have also been manufactured in three sizes,—0.125 ($\frac{1}{8}$) of an inch in diameter, 0.156 ($\frac{5}{32}$) of an inch in diameter, and 0.187 ($\frac{3}{16}$) of an inch in diameter. The first is threaded twenty-four turns to the inch; the second, twenty-four turns to the inch; and the last, twenty turns to the inch. The screw, one-eighth of an inch in diameter, is used in most cases. However, it should be pointed out that in threading this screw, a die must be used that does not cut so deeply that it unduly weakens the shaft of the screw. The screw has a sharp triangular point. The smallest size is capped with a quarter-inch hexagonal head of the same material as the shank, while the two larger sizes are capped with hexagonal nuts, three-eighths of an inch in diameter. The long diameter of the hexagonal head is also one-quarter of an inch. The head is slotted for application of the screw driver. The material used in the screw is one of the stainless steels (18 per cent. chromium, 8 to 10 per cent. nickel). Determinations of tensile strength in longitudinal-pulling tests show that the smallest screw will not give way—that is, the threads will not strip—until an average of 800 pounds has been applied; the second size will withstand 1,130 pounds; and the last size, almost 1,300 pounds. In these tests, the shank never broke, but the threads stripped. Tests of the holding power of four or five screws in experimental fractures of the central portion of the femoral neck in specimens removed from cadavera showed that a distracting force of 600 to 800 pounds was required to separate the fracture, while the screws in a similar situation would withstand a shearing force of from 500 to 1,200 pounds before the screws cut through the femoral head. The details of these tests and comparison of the results of them to the results of tests of other screws and materials used for the fixation of transcervical fractures of the upper femur will be presented in another communication. In the tests of distraction, it was found that the hexagonal heads occasionally cut through the lateral cortex of the femur at the site of entrance of the screws. Such cortical breaks always occurred when the screw had been introduced into the lateral femoral cortex in the inch immediately distal to the greatest lateral prominence of the trochanter (vastus externus line). Consequently, it has now become our practice to distribute the pressure in this area by thin, stainless-steel washers with an outer diameter of one-half inch or by a small methyl methacrylate plate. When the point of entrance of the screw was placed more inferiorly, a thicker osseous cortex was engaged, which did not give way. The maximal distracting force of 800 pounds or more would then pull the head of the femur from the screws.

* Read at a meeting of the Chicago Orthopaedic Society, April 14, 1944, and in part at a meeting of the Columbus, Ohio, Academy of Medicine, October 16, 1944.

The insertion of these screws is started with a drill, equipped with an adjustable chuck. When the entering course of the screws has been definitely determined, the drill is removed and the screw is more quickly and firmly twisted home with a brace, equipped with a quarter-inch socket attachment (Fig. 1-B).

INTERNAL FIXATION

Transcervical Fractures

It is almost universally agreed that internal fixation of transcervical fractures of the hip from the trochanteric side is preferable to arthrotomy. Moore pins and the Smith-Petersen nail offer little or no resistance to a distracting or sliding force directed in the long axis of the femoral neck. This allows intrusion and extrusion of the nail or pins. Telson

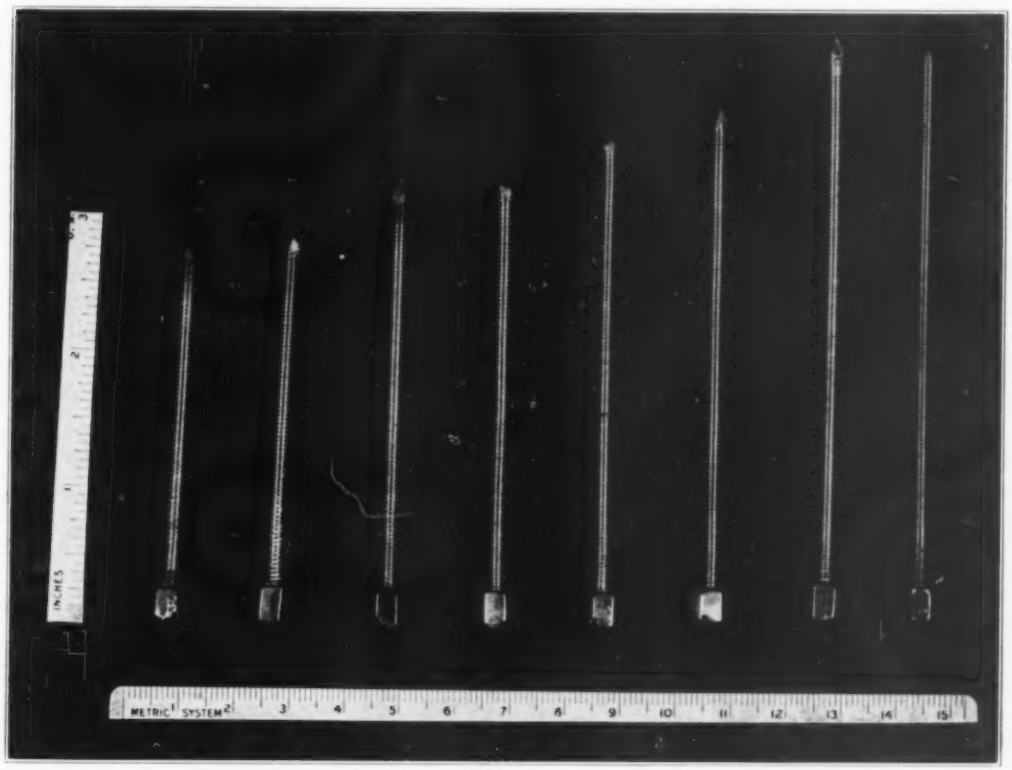

FIG. 1-A

Slender, hexagon-headed, stainless-steel screws of various lengths, as used in fixation of the transcervical femoral fractures.

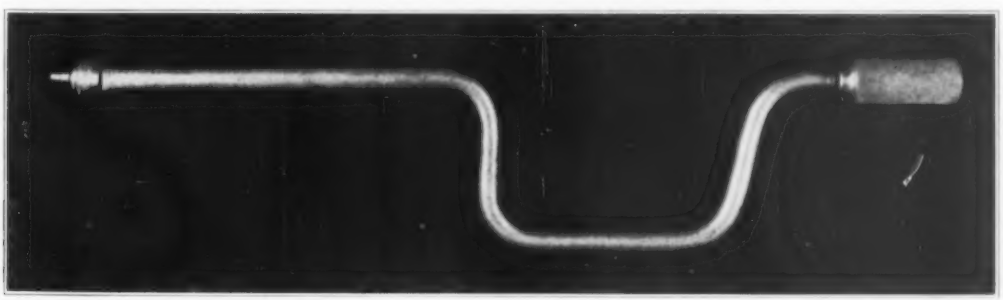

FIG. 1-B

Socket brace to fit hexagon-headed screws, the heads of which are one-quarter of an inch in their transverse diameter.

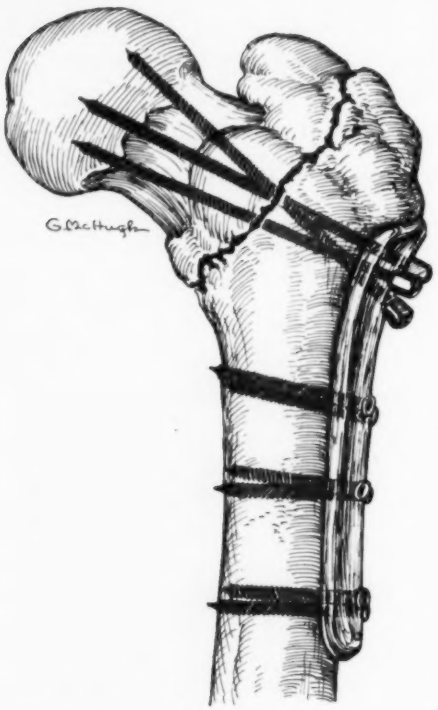

FIG. 2

Artist's sketch, showing the position of the plate and screws in a typical trochanteric fracture.

and Ransohoff, and Chester have reported satisfactory experience with Kirschner wires, but it later became evident[22] that the wires might migrate. Slender, uncapped, threaded wires have been observed by us and by others to migrate, and, in rare instances, to perforate the pelvis.

Trochanteric Fractures

Not so generally accepted is the open reduction and internal fixation for fractures in the trochanteric region. A high mortality has been reported for trochanteric fractures, treated by methods ordinarily referred to as "conservative". Leydig and Brookes reported a mortality rate of 39.2 per cent. in 302 cases of trochanteric fracture at the St. Louis City Hospital; Taylor, Neufeld, and Janzen, 25 per cent. in 165 patients from the Los Angeles County General Hospital; Wilson, 24.3 per cent. in sixty-two patients in the Massachusetts General Hospital; Morris, 44 per cent. in sixteen patients at the Charity Hospital in New Orleans, while the mortality in 164 cases at the Guthrie Clinic and Robert Packer Hospital (private and ward cases combined) over a ten-year period ending in 1941 has been 39.0 per cent. These ratios do not tell the whole story. Comfort to the patient in freedom of motion in bed, transfer to the wheel chair, and early crutch ambulation with consequent lack of complications, including decubitus, are the chief advantages of internal fixation. Two of our patients, who have been unfortunate enough to have had earlier hip fractures treated "conservatively", stated that they prefer the internal fixation.

Key was the first to attempt internal fixation in these fractures, and to report some of the problems involved. It was his opinion that the low trochanteric fractures, in which the lateral cortical shell was comminuted or was carried with the upper fragment, could be fixed only by wiring. Since that time the use of the Thornton plate, in conjunction with the Smith-Petersen nail and other devices, has demonstrated that internal fixation which prevents adduction and rotation of the distal fragment will maintain reduction.

The principles enumerated above have been met by different men with various devices.

The author's screws, similar to but longer and more slender than those described by Geckler for the fixation of transcervical fractures, depend upon fixation in the lateral femoral cortex to maintain abduction without rotation, and hence the proper cervical angle. In this report are given our experiences with fixation of these fractures with a molded plate of non-irritating plastic (methyl methacrylate), fixed to the reduced fragments with stainless-steel screws of the construction described. Figure 2 shows the diagrammatic application of the principle.

The trochanteric fractures are a heterogeneous group, varying from a simple fracture at the base of the femoral neck (just without or at the insertion of the capsule) to complex comminuted fractures of the trochanters. These latter fractures in turn grade off into the comminuted and spiral subtrochanteric fractures.

The results reported by others in the internal fixation of trochanteric fractures have been encouraging: Morris reported 21.4 per cent. mortality in twenty-eight cases at the

TABLE I

RESULTS IN THE TREATMENT OF FRESH * TRANSCERVICAL FRACTURES WITH STAINLESS-STEEL SCREWS (THIRTY-FIVE CASES)

Result	No. of Cases	Per Cent.
Satisfactory union with a viable head	31	88.6
Early necrosis of the femoral head (minimal period of follow-up, 1 year; maximal follow-up, 3 years)	0	0.0
Union by osteotomy, performed within six months of fracture	3	8.6
Non-union †	1	2.8
Immediate hospital mortality	0	0.0
Mortality within first year after pinning (from unrelated causes)	0	0.0

* All but two patients were brought to the Hospital on the day of the fracture,—the majority within four hours. The other two patients were seen on the second day.

† The non-union was caused by an unsatisfactory primary reduction. It was thought unwise to attempt second reduction and fixation, since the patient was a poor operative risk and was blind and bedridden.

Charity Hospital, New Orleans; Key, a "lowered mortality"; Jewett, no mortality in five cases; and Thatcher, one death among thirteen patients who were operated upon. Moore reported forty-one cases fixed with the blade-plate out of a total of eighty-three cases of trochanteric fractures treated by open operation without a fatality. The mortality rate in our series was 11.1 per cent. (five out of forty-five cases), but the causes of fatality were the usual ones in elderly patients who had not been operated upon, and occurred several weeks after the operation. None of these fatalities occurred in private patients. This mortality is less than one-third that observed in a similar group of patients in the same hospital, who had been treated in previous years by "conservative" methods (Table II). The average hospital stay of eighteen patients with trochanteric fracture treated by operation in Morris's series was twenty-nine and one-half days; the average stay of forty surviving patients in this series was forty days.

MANAGEMENT OF THE PATIENT AND OPERATIVE TECHNIQUE

Patients who have sustained hip fractures are considered to be emergency cases. As soon as roentgenograms of the hip have been made, the patient is transferred directly to a fracture bed, and the Thomas or other ring splint, which has been used for emergency transportation, is removed. Fifty to eighty cubic centimeters of 0.5 per cent. procaine is injected about the hip; traction is applied through a Steinmann pin inserted above the condyles of the femur; and the limb is supported upon a Braun frame. That reduction takes place within a few hours of the time the patient is thus arranged in bed can be demonstrated by roentgenograms taken the next morning. Reduction may be expected in all cases except certain transcervical fractures which offer resistance to reduction by traction, because of their peculiar displacement (usually posterior rotation of the proximal

TABLE II

RESULTS IN THE TREATMENT OF TROCHANTERIC FRACTURES WITH METHYL METHACRYLATE PLATES AND STAINLESS-STEEL SCREWS (FORTY-FIVE CASES) *†

Result	No. of Cases	Per Cent.
Satisfactory union without shortening	40	88.8
Necrosis of the femoral head	0	0.0
Early coxa vara, detected by routine roentgenograms, and subsequently treated by additional traction in bed	3‡	6.6

* The immediate hospital mortality from the usual causes in patients of advanced years and unrelated to the operation was five cases, or 11.1 per cent.

† Additional mortality occurring within two years of leaving the Hospital (from unrelated causes) was ten cases, or 22.2 per cent.

‡ These cases were included in the forty, because the end result was good.

FIG. 3-A

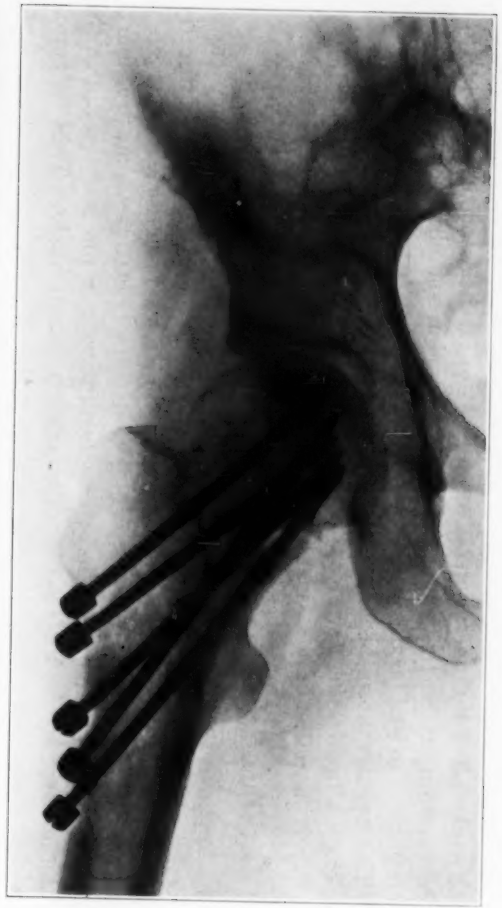

FIG. 3-B

FIG. 3-C

Case 1. Roentgenograms of a transcervical fracture in a woman, sixty-nine years old. Firm osseous union was obtained in four to six months following immobilization by five stainless-steel screws.

Fig. 3-A. Roentgenogram taken on admission to the Hospital.

Figs. 3-B and 3-C. Anteroposterior and lateral roentgenograms taken seven weeks after operation.

FIG. 4-A

FIG. 4-B

Case 2. Preoperative and postoperative roentgenograms of a double fracture, with an intermediate free fragment. The superior fracture line is transcervical, while the inferior fracture line is a combination trochanteric and spiral subtrochanteric fracture. The long five-inch methyl methacrylate plate was used, and the inferior tip of the superior fragment was anchored at the lower fracture line by means of two loops of stainless-steel wire.

fragment). The open reduction is carried out with the patient in bed in the operating room (Fig. 5); a wooden cassette tunnel which is transparent to roentgen rays, is placed beneath the hips. The day of operation varies from one to four days following the fracture. It is our experience that one-third of these elderly patients have diabetes mellitus, and almost all of them have a moderate degree of secondary anaemia. Every patient routinely receives a blood transfusion of 500 cubic centimeters following operation; some patients receive preoperative transfusions and more than one transfusion following operation. We consider the transfusions important, although shock, as evidenced by a reduced blood pressure, is seldom seen. Following operation, most patients are out of bed in the wheel chair for a few hours daily, but ambulation, even with crutches, is not allowed for three months in patients who have suffered transcervical fractures, and for eight weeks in the case of those with trochanteric fractures. In complicated fractures, the patients are kept recumbent, without being allowed in a wheel chair, for fourteen to sixteen weeks. After six weeks, all patients are given active and passive knee exercises on the Böhler exercising frame.

DISCUSSION AND RESULTS

The results of the treatment of thirty-five cases of fresh transcervical fracture are given in Table I, from which it is seen that we have obtained satisfactory union with a viable head in 88.6 per cent. of the cases. If an open fracture line is still present six months

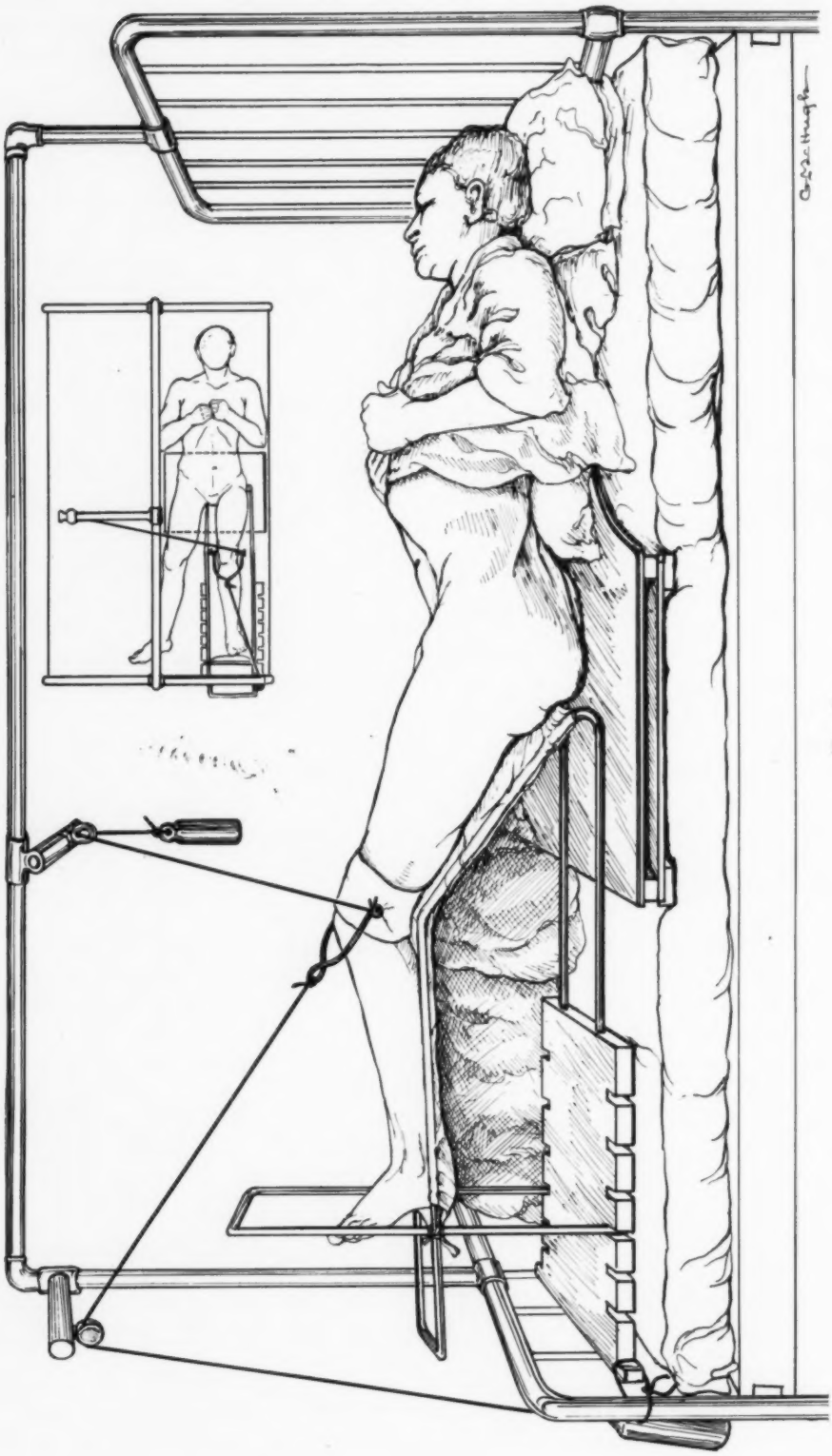

FIG. 5

Drawing, showing the position of the patient in bed at the time of the operation. The limb and the site of the fracture are immobilized by skeletal traction on the Braun frame. A wooden cassette holder which is transparent to roentgen rays, is beneath the hips to facilitate the taking of roentgenograms during the operation.

after operation, it is our practice to remove the screws and perform a subtrochanteric osteotomy, fixing the fragments with the Moore-Blount blade-plate. If three cases in our series, which were subsequently treated by osteotomy, are included, then satisfactory union with a viable head was secured in 97.1 per cent. The early reduction that we were able to secure in these cases presumably caused a minimal interference with the blood supply to the head along vessels which remain in the untorn portion of the reflected capsule of the neck, this possibly being the reason for the non-occurrence of early necrosis of the femoral head. This percentage of union in this type of fracture compares well with those listed in Callahan's review in 1939, which summarized the results obtained by various authors to that date. Since then, Cleveland has reported osseous union in 86 per cent.; Felsenreich, in 93 per cent.; Henderson, in 81 per cent.; King, in 93 per cent.; Semb, in 94 per cent.; and Valls and Lagomarsino, in 82 per cent. All utilized the Smith-Petersen three-flanged nail. Moore has reported 96 per cent. union, utilizing his special nails. The percentages of union listed above are based on the number of patients who survived the period of hospitalization.

The special advantage in the use of a threaded appliance is the elimination of all motion following fixation. We have had no instances of "absorption of the neck" and, therefore, no instances of intrusion of the fixation appliance through the femoral head and acetabulum, as is occasionally seen when non-threaded appliances are used. Tests performed upon experimental fractures of the neck of the femur in moist cadaver specimens indicate that the best fixation is secured when the screws are placed in the periphery of the neck, especially when two or more screws are placed just within the inferior cortex of the neck in a diagonal direction from a point several centimeters below the vastus externus line. This plan has been followed in the cases included in this report.

Table II shows that we secured satisfactory union without shortening and without additional treatment in 88.8 per cent. of the cases (forty out of forty-five cases) of trochanteric fractures. This includes three cases in which the fixation did not appear to be adequate enough to prevent the recurrence of slight coxa vara, and which were subsequently treated by additional traction in recumbency, with a good result. Whether or not the mortality before and after leaving the Hospital indicates that the patients suffering from trochanteric fractures are more fragile than those suffering from transcervical fracture, as is claimed by certain authors [13, 26], cannot be shown conclusively by the small number of cases of this report (Table II). There was no instance of decubitus, thrombophlebitis, or pneumonia among the patients suffering from trochanteric fractures. Their ability to be about in a wheel chair, free from traction, a number of hours each day contributed to their well being.

CONCLUSIONS

1. A new type of slender, long, threaded, stainless-steel screw has been described. The advantage of a screw in the fixation of hip fractures is that it obtains and holds impaction of the fragments.

2. The upper lateral femoral cortex is the site of counterpressure for this impacting force, which should be diffused by steel washers or plastic plates.

3. In the fixation of trochanteric fractures, it is necessary to use a plate extension, fixed by the screws to the lateral cortex of the upper femoral shaft to maintain internal rotation, and to counteract the tendency to redisplacement.

4. The important principles in the management of patients with these fractures are early reduction, fixation following an anatomical replacement of fragments, a postoperative regimen sufficiently flexible to avoid decubitus and other ills of prolonged and enforced recumbency, and the avoidance of ambulation (even with crutches) until union is well under way.

5. The results in thirty-five cases of fresh transcervical fractures include satisfactory

union with a viable head in 88.6 per cent. of cases. Union was secured by subtrochanteric osteotomy (the necessity of the operation indicated by an open fracture line in the roentgenogram six months after fixation) in three additional cases or a total of 97.2 per cent. There were no fatalities in this series, and no cases of early necrosis of the femoral head. Since the cases have been observed for only one to three years after operation, no statements can be made about late necrosis of the femoral head.

6. The results in forty-five cases of trochanteric fractures include satisfactory union without shortening in 88.8 per cent. Mortality from the usual causes among aged patients was observed in this group in five cases (11.1 per cent.). This represents a reduction of mortality to less than one-third that observed in a larger series of cases treated "conservatively" in the same Hospital over a ten-year period preceding this study.

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MEASUREMENT OF MUSCLE STRENGTH

BY HENRY MILCH, M.D., NEW YORK, N. Y.

Destructive criticism has never been too highly appreciated, and negative discoveries have never won the Nobel Prize. Yet each may play a valuable and vital rôle in the progress of science and may serve to avoid waste of effort that could profitably be directed along other lines. This seems to be true of present methods of estimating muscle power, especially with respect to the possibility of muscle transplantation.

Though the practice of muscle transplantation has by far not fulfilled the earliest hopes and expectations with which it was received, it still remains one of the major methods in the effort to rehabilitate the paralytic patient. Many pitfalls of a technical nature beset its path, but probably the most serious is the inability accurately to gauge the actual strength of the patient's remaining musculature. Without such prerequisite estimates, it would seem impossible to avoid the danger of inadequately correcting the existing deformity, or, by overcorrecting, of creating the opposite deformity. Without such records, the merit of methods already devised to improve the functional capacity of the patient cannot be critically evaluated or a rational therapy established.

The evident need for such data is indicated by the elaborate muscle charts which have been made a part of the medical history of paralytic patients. Though such charts may have value for comparative purposes in any given individual, though they may permit of analytical study of certain types of muscle imbalance, it must, however, be seriously questioned whether they represent what they purport. Do such charts, even when accurate, really give information as to the *actual* strength of muscles? Is it possible to measure muscle strength under ordinary clinical conditions? Are such measurements as are obtained directly applicable to the problems of the orthopaedic surgeon? The answer to these questions appears to be in the negative. In consequence, it seems that the value of these charts must be accepted within much narrower limits than has usually been accorded them.

It is not unlikely that a large part of the difficulty arises from a confusing equivalence of the concepts of "muscle strength", with that of "work done by muscle". Since "work

done" or torque is, by definition, the result of muscular strength acting upon a lever arm, it is clear that the measure of torque cannot by any means be considered as the measure of muscle strength. For practical purposes, this differentiation is of paramount importance. It is muscle torque of which the patient becomes aware, but it is muscle strength which the surgeon transplants, with the object of modifying torque.

The determination of muscle strength implies the ability to measure the strength of an isolated muscle-nerve unit. Except in laboratory animals under experimental conditions, such observations have been impossible by ordinary clinical methods. Some progress in the solution of the clinical problem has recently been achieved by the study of electromyograms made with coaxial needle electrodes. In general, it has been found that muscle activity is characterized by the generation of a diphasic current which can be measured and recorded. Hoefer and Putnam reported that, in normal resting muscles, no such currents could be recorded. On the other hand Hoefer noted that "effort and the frequency and height of action potentials are roughly proportionate". Watkins, Brazier, and Schwab[4] noted that "action potentials were studied during voluntary contractions such as are required during an ergographic test. The voltage of these discharges was found to be proportional to the degree of strength and gave indication of the rate of restoration of function." However, neither by the measurement of electric potential nor by the determination of voltage-capacity curves were they able to establish a numerical relationship between the strength of any given muscle and the observed electrical phenomena. To estimate the so-called strength of the muscle, recourse had still to be made to a refined ergographic apparatus[3].

The determination of work capacity lies at the basis of all present methods of measuring muscle strength. For the purpose of comparing the degree of improvement in any given muscle, a quantitative ergogram may have definite value; but fundamentally it gives no more objective determination of individual muscle strength than is obtained by the simplest clinical method in which the muscles are roughly classified as falling into one of a varying number of subgroups. The lowest grade, zero, is given to those muscles in which there is complete absence of power. The highest, grade six, is given to those in which the muscle power is normal. The intermediate grades are assigned categorically to muscles which possess the power of movement; of movement against gravity; of movement against resistance; and so on. Primarily, the objection to this system of notation has been its subjective character. The effort to eliminate such estimates in favor of more objective determinations has naturally led to the development of elaborate and ingenious measuring devices. While admitting the desirability of objective observations, it is questionable whether resolution of the difficulty has been advanced in any notable degree by the use of so-called scientific methods. The high degree of elegance which the more recent efforts have reached cannot ignore the fact that earlier and equally clever attempts at mechanical solution of the problem have met with neither success nor universal approval.

The reason for this is not far to seek. Except in the hypothetically isolated muscle-nerve unit, work is normally accomplished by synergistic action of several muscles or muscle groups. Each muscle may have several components of action and each supplies only a small component of the action under study. Since it is impossible to determine at any given moment the particular contribution of each of the synergists, it is evident that the tabulation of individual muscle strength is almost wholly valueless. It is the magnitude of flexion, extension, adduction, and abduction around a joint axis, rather than the power of the individual flexor, extensor, or adductor crossing the joint which can be recorded. The ergographic record obtained by any method is the resultant of many muscle actions, rather than the measure of a single muscle force. This is a matter of primary importance, and leads logically to the necessity for determining the meaning of the observed numerical value of this resultant.

Smooth, physiological muscle action implies the synergism of antagonist as well as

protagonist muscles or muscle groups. Any motion about a joint is inconceivable without contraction of one group of muscles and simultaneous relaxation of its opposing group. The very fact of motion indicates a resultant force which measures the preponderance of any group over the other. The actual strength of the one group is clearly greater than the numerical value of the resultant by the amount of power exerted by the opposing group. Here, too, no definite knowledge is obtainable. Some students are of the opinion that the power of the antagonist gradually decreases as the agonists contract. Others believe that the antagonists constantly exert the full force of their inherent tonus. Still others present evidence to prove that residual tonus may be completely abolished under physiological conditions. In any event, the situation seems to be somewhat different in normal and in diseased muscles.

Hoefer has expressed the opinion that in normal muscles "tonus" originates in motor stimuli of low amplitude and low frequency in the antagonist muscle. The fact that normal resting muscles disclose no such discharge may be taken to indicate that these stimuli are below the threshold of recognition. The difference between the relaxed flaccidity of "dead" muscle and the alert tension of living muscle is clear evidence of the presence of some force, "tonic" or "elastic", which is in opposition and normally reduces the measured force of the muscle under observation. In paralytic muscles, a somewhat different situation arises. Watkins, Brazier, and Schwab[4] report, "we have found objective evidence, however, of 'incoordination' in poliomyelitis. The simultaneous activation of protagonists and antagonists was a striking feature of our electrical recordings. . . . The fact that this synchrony of muscle discharges was observed also during regeneration of peripheral nerves after injury leads us to believe that it is a phenomenon associated with a regenerative process. . . . The so-called 'incoordination' in patients with poliomyelitis may also be an example of abnormal function following regeneration."

Whether the counterforce originates in muscle tonus or elasticity or in the incoordination of the antagonists, it must be apparent that the resultant, even when objectively determined, can only have an indeterminate significance. Either for the purpose of accurately estimating changes in muscle strength or as means of preoperatively determining the availability of a muscle for transplantation, implicit acceptance of the mathematical value of such a resultant as an established scientific fact may be completely misleading. This can be illustrated by suitably selected instances.

Any physiological muscle imbalance, such as occurs for example in the act of extension, represents a preponderance of extensor effort over the work done by the antagonist flexors. While this preponderance is measurable on any ergographic scale, the observed reading gives no information as to the actual work done by either muscle group. Thus a reading of 65 units might represent the difference between 100 and 35 or between 66 and 1.

However, the difficulty is even more serious than these simple illustrations make it appear. Suppose that by some hitherto undescribed method the reader, alone, could discover that the actual strength of the flexors in a paralytic patient was 50 units, while the actual strength of the extensors was 35 units. Assuming that the "residual tonus" or counterforce were approximately 10 per cent. of the actual strength of the antagonist, a suitably calibrated measuring device would indicate a flexor strength of 50.0 minus 3.5 or 46.5 units (the strength of the flexors less 10 per cent. of the strength of the extensors). The extensors, on the other hand, would appear to possess a strength of 35.0 minus 5.0 or 30.0 units. While the actual difference between the two muscle groups was only 15 units, the ergograph would indicate a flexor imbalance of 16.5 units. Though this could have been much more readily determined by clinical examination, the magic of numbers seems to lend especial objectivity to the determination. However, if the matter is pursued still further, it will be discovered that the magic is rather dark and may lead to erroneous conclusions.

To overcome the flexor contracture, traction, electrical stimulation, and other forms of

therapy can be instituted, but widely differing results may be obtained. In one patient, improper treatment might be followed by an actual decrease in the strength of the extensors from 35.0 to 10.0 units (the flexors remaining unaffected at a strength of 50.0). On the ergograph, the strength of the extensors would seem to have been decreased to 5.0 (10 minus 5) units, while the flexors would appear to have increased somewhat in strength to 49.0 (50 minus 1) units. The disappointment of the examiner at the apparent sixfold decrease in the power of the extensors would be with as little basis in fact, as his unwarranted satisfaction at the deceptive increase in the power of the flexors.

Under other circumstances, the actual strength of the extensors might have increased to 90, while the flexors remained unchanged. The measuring device would seem to indicate that, along with the marked increase in the extensors to 85.0 (90 minus 5) units, there had occurred a real decrease in the strength of the flexors to 41.0 (50 minus 9) units. Though the complete reversal of the muscle imbalance would have been clearly demonstrated, no small part of this would erroneously be attributed to an illusory decrease in flexor strength.

Examples such as these could be multiplied, but to no purpose other than to direct attention to the extreme caution with which such apparently objective observations must be interpreted. If this be true for measurements made for purposes of comparison, it is true to an even greater degree when such measurements are made the basis of surgical intervention. In a hypothetical case of flexion contracture due to a muscle imbalance between flexors (actual strength 90 units) and extensors (actual strength 50 units), the real difference would be 40 units. Making due allowance for the effect of tonic resistance, meter readings would indicate a flexor power of 85.0 (90 minus 5) units, an extensor power of 41.0 (50 minus 9) units, and a flexor preponderance of 44 units. Accepting these readings at their face value, it would seem that muscle balance at 63 units could be effected by a transfer of 22 units from the flexor to the extensor group. However, by actually transferring 22 units of muscle power from the flexors to the extensors, the real value of the flexors would be reduced from 90 to 68 units, while the real strength of the extensors would be increased from 50 to 72 units. In fact, the flexor contracture will have been converted into an extensor contracture. On the ergograph, the extensors would register as 72.0 minus 6.8, or 65.2 units. The flexors would register as 68.0 minus 7.2, or 60.8 units. The actual extensor preponderance of 4 units would appear on the measuring device to be equal to 4.4 units.

Consideration of these different drawbacks make the efforts at precision measurement of muscle strength by ergographic methods somewhat futile. But even these become relatively unimportant, when the problem is viewed in the perspective of those other factors which exert a dominating effect on the outcome of muscle transplantation. The work performed by any muscle depends not only upon its power, but upon the angle of application of the power upon the motivated lever arm and the length of the lever through which the power is applied. It is greatest when applied at right angles to the lever arm, and, in general, is expressed by the formula $P' = P \sin x$. The value of the angle x is to be determined, not by the angle of insertion of the tendon into a given bone, but by its inclination to the lever arm, which is the resultant of all the bones between the muscle insertion and the axis of rotation at the joint. Axial deviations of this nature may so profoundly modify the effective power of a transplanted muscle that the quantitative measurement of its original position cannot be accorded any greater dignity than that of historical interest for all other positions.

Similarly, any change in the length of the lever arm upon which the muscle works will completely alter any judgments made on the basis of preoperative measurement of muscle strength. Since work done is equal to the product of the power by the length of the lever arm ($W = P \times L$), a relatively slight variation in L may lead to a totally unexpected change in the result desired. Thus, if a muscle, normally inserted one inch from its ful-

crum, were to be inserted only one-half inch closer to its new axis of motion, the power of the transplanted muscle would be reduced to half. An opposite variation would increase the muscle strength by an amount proportional to the increase in the length of the lever arms. Faced with the possibility of such wide variations, surgical procedures would have to be carried out with theodolite precision to be commensurate with the supposed accuracy of muscle-strength determinations.

The inability accurately to control or positively to determine all of these factors markedly narrows the field of application of the usual type of muscle-strength determinations. While the possibility exists that, in the future, measurements made by the use of some other principle may be devised, the methods at present employed must be accepted merely as more or less accurate clinical estimates of muscle strength. In the respect that they tend to minimize the subjective character of present methods, they represent some advance and may serve for purposes of comparison. Insofar as the actual measurement of individual muscle strength is concerned, the hope placed in ergographic determinations appears to be entirely chimerical. The pseudoscientific enumeration of the work capacity of a long list of individual muscles as a basis for surgical intervention is misleading and should be discontinued. At most, muscle charts should indicate the relative strength of flexion, extension, adduction, abduction, or rotation possible at the joint under consideration. They can never be elaborated so as to replace clinical judgment, which must finally be brought to the analysis of the surgical problem. The decision as to the availability or desirability of any muscle transplant still remains a question of individual surgical judgment. No amount of objective measurement of work capacity can be substituted for the subjective estimate of the experienced surgeon.

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AN OPERATION FOR THE CORRECTION OF LOCKING OF THE PROXIMAL INTERPHALANGEAL JOINT OF FINGER IN HYPEREXTENSION

BY MAJOR JOHN T. BATE

Medical Corps, Army of the United States

J. G. R., an aviator, was admitted to Thayer General Hospital January 17, 1944, complaining that he was unable to taxi a four-motored plane satisfactorily, because of locking in hyperextension of the proximal interphalangeal joint of the right fifth finger. To properly control the plane, it was necessary to grasp a control instrument with the right hand, using the index finger to regulate the motor on the extreme left, and the fifth finger to regulate the motor on the extreme right. When he quickly grasped this instrument (a type of throttle), the fifth finger would lock. He could not flex the finger again, until he had used his left hand to start the flexion. It was then possible to actively continue the flexion to its normal completion.

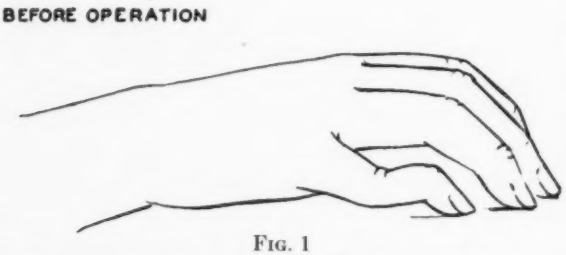

FIG. 1

Drawing showing the fifth finger locked at the proximal interphalangeal joint.

FIG. 2

Roentgenogram showing the position in which locking occurred.

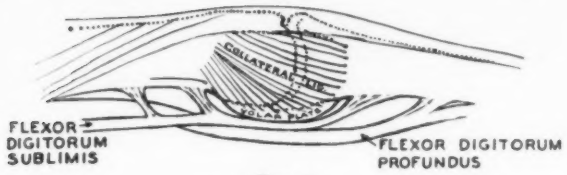

FIG. 3

Diagrammatic sketch showing the anatomy of the proximal interphalangeal joint of the finger.

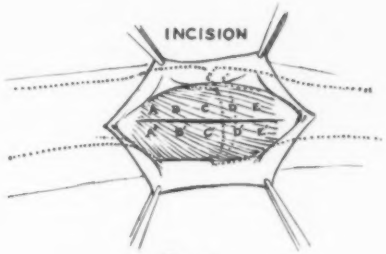

FIG. 4

Sketch showing the line of incision through the lateral part of the capsule of the proximal interphalangeal joint. The lettering helps to illustrate the method of repair (See Fig. 7).

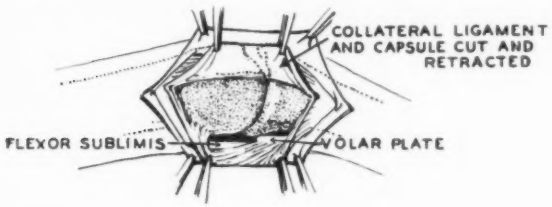

FIG. 5

Drawing of the tear on the volar portion of the capsule.

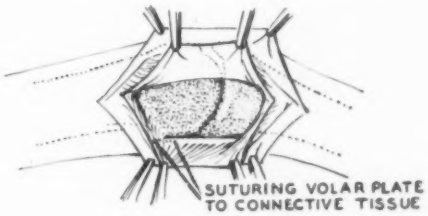

FIG. 6

Drawing showing the repair of the volar plate of the capsule.

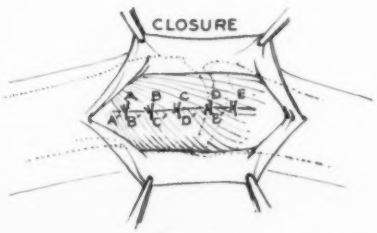

FIG. 7

Sketch illustrating the suturing of the lateral capsule by a method which shortens the anterior portion of this part of the capsule.

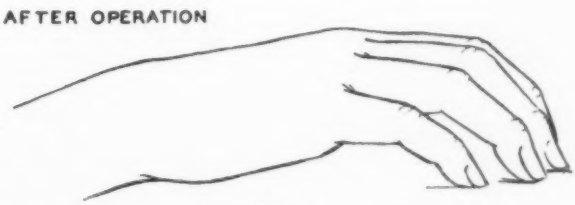

FIG. 8

Sketch showing the final result of the operation.

As we had not previously encountered this condition, and were unable to find a description of its repair in the literature, considerable thought was devoted to the problem because the officer's army and civil aviation future depended on its successful solution.

His history revealed that on August 4, 1943, while engaged in basket-ball practice, he had been struck on the end of the right little finger with a basket ball. He reported to sick call and the finger was splinted; no roentgenogram had been taken. He continued on duty, but noticed that the finger was easily injured thereafter, and that the proximal interphalangeal joint remained swollen.

About October 24, 1943, he had again injured the right fifth finger at the proximal interphalangeal joint while playing baseball. He was not wearing a splint at this time.

Since October 1943, he had had marked instability of the right little finger, and he had been unable to use it to control the throttle on a four-motored plane. The finger frequently came out of joint, was sore, and greatly interfered with duty.

Physical examination was negative except that the right hand showed marked instability of the proximal phalangeal joint of the fifth digit. Forced flexion produced discomfort in this joint. Extension caused the joint to push forward into hyperextension of about 15 degrees.

An operation was performed on January 31, 1944, under intravenous sodium pentothal. A tourniquet was applied at a pressure of 200 millimeters, and an incision was made along the lateral surface of the right fifth finger at a point between the volar and dorsal nerves and vessels. The lateral surface of the joint was opened through the strong fascial capsule. When this was retracted, it was found that there was no volar capsule. The flexor tendon could be seen running through some areolar tissue. The lateral attachment of

the flexor digitorum sublimis tendon was intact. The capsular structures on the volar surface of the joint were dissected back about four millimeters. The contracted volar ligament, still attached to the proximal part of the middle phalanx, was sutured to the proximal phalanx on the anterior surface. This suture prevented hyperextension of the joint. The lateral capsule was then repaired in such a manner as to shorten the volar side by suturing it more proximally. This prevented complete extension of the joint; it remained flexed about 30 degrees.

The fourth and fifth fingers were then dressed in flexion over a two-inch gauze bandage, and held in place by means of adhesive tape and bandage.

The postoperative diagnosis was posttraumatic dorsal dislocation of the interphalangeal joint of the fifth finger, of a chronic and recurring type.

The postoperative course was good.

February 1, 1944: He was ambulatory, with the right arm in a sling. The hand was comfortable.

February 7, 1944: The sutures were removed. There was no infection.

February 22, 1944: The dressing was removed and an aluminum splint was applied, which held the fifth finger in flexion of 30 degrees at the proximal interphalangeal joint.

February 24, 1944: He returned to partial duty.

April 30, 1944: The following report was received: "I have seen the patient several times and he really has an excellent result. There is extension to about 160 degrees and no limitation of flexion. He is back on flying status and is able to use the throttle quite well. I have suggested that he get a hand-ball to carry in order to strengthen his grip. There is only slight weakness of the fifth finger which should improve with exercise."

May 4, 1944: Another report read: "He resumed his flying duties on March 21. There has been no sign of locking of the fifth finger at the proximal interphalangeal joint and the flyer has been able to resume full duty with respect to flying four-motored planes. The operation is considered very successful. . . ."

NOTE: Through the courtesy of Dr. Samuel Clark, Professor of Anatomy at the Vanderbilt University Medical School, it was possible to dissect a fifth finger in order to work out the details of the anatomy, shown in the drawings by the artist, Miss Susan H. Wilkes.

BILATERAL SYMMETRICAL BRACHYMETACARPALIA AND BRACHYMETATARSALIA

Report of a Case

BY MAJOR FREDERICK J. FISCHER AND CAPTAIN ROBERT E. VANDEMARK

Medical Corps, Army of the United States

Bilateral symmetrical shortening of the fourth metacarpal and of the fourth metatarsal in one individual is an extremely rare anomaly. Boorstein has reported an apparently similar, if not identical, condition in a patient who gave a history of the anomaly in nine other members of her family. The rarity of the anomaly warrants the report of an additional case in which the deformity was not present in any known relative.

CASE REPORT

A private, twenty-six years of age, was admitted to Bruns General Hospital on April 21, 1944, with a transfer diagnosis of (1) bilateral, congenital deformity of the two distal phalanges of the fourth and fifth toes, and (2) hypertrophic arthritis of the ankles. On admission, the patient's chief complaints were (1) pain in the left leg at the site of a varicosity, and (2) pain in both feet on prolonged standing, walking, or drilling. Since early childhood, he had noted that his hands and feet were different from those of other people; his parents knew of no one in the family who had a condition similar to his. In adult life his feet became painful; relief could be afforded only by limitation of activity.

Examination of the feet showed, at first glance, apparent bilateral shortening of the fourth toe (Fig. 1); however, further examination showed symmetrical shortening of the fourth metatarsals, with plantar calluses under the fourth metatarsal heads. The hands appeared relatively normal with the fingers extended (Fig. 2).

Fig. 1

but flexion of the metacarpophalangeal joints showed symmetrical shortening of the fourth metacarpals (Fig. 3). The condition of the patient's hands caused no complaint. Examination of the ankles was negative.

As an incidental finding, numerous dark brown pigmented areas, varying in size from two to fourteen millimeters, were noted on the trunk and the limbs; some of these areas were elevated above the surrounding skin surface, while others were not. The patient stated that these pigmentations were present in most of the members of his family. Because of the excessive complaints of pain at the site of the mild varix on the lateral aspect of the distal left leg, the patient was seen by a surgical consultant, and later by a neuropsychiatric consultant, who made the diagnosis of a moderately severe hysteria. In view of the latter diagnosis, it was recommended that no surgical treatment of the varix be undertaken, since elaboration and fixation of symptoms might result.

Roentgenographic examination showed bilateral symmetrical shortening of the fourth metatarsal

FIG. 2

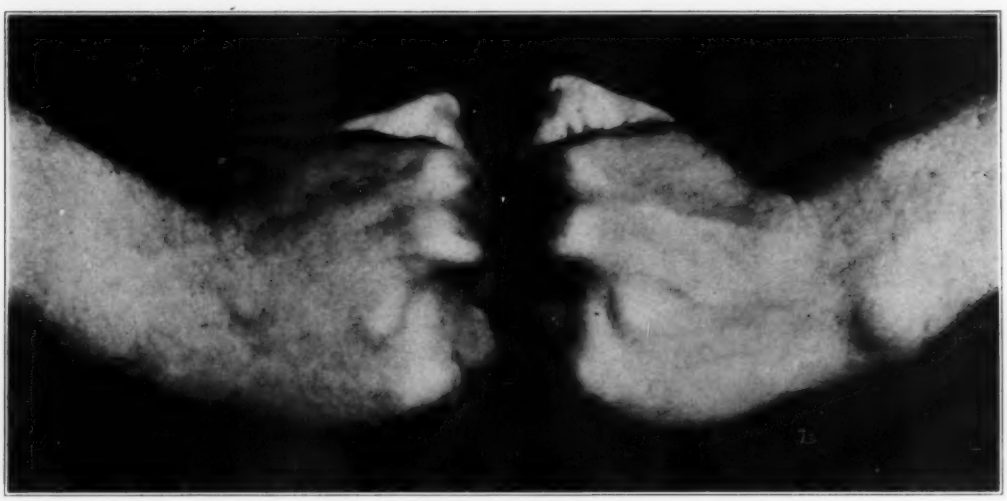

FIG. 3

FIG. 4

(Fig. 4), and bilateral symmetrical shortening of the fourth metacarpal, with very slight relative elongation of the phalanges of the ring fingers (Fig. 5). The proximal phalanx of the fourth toe on the left was equal in length to that of the fifth, while on the right it measured slightly less, due to a hyperextended position of the toe. The ankles appeared normal on the anteroposterior and lateral views. Examination of the urine and the blood, including the serological test and the sedimentation rate, revealed no abnormalities.

On the recommendation of the Air Corps Consultant, the patient was discharged from the Hospital to limited duty, with the provision that he be assigned to duties that involved no prolonged standing, walking, or drilling.

DISCUSSION

Previously, congenital shortening of a metacarpal or of a metatarsal has been termed brachydactylia, which is defined as shortening of the fingers or toes. In this case, shortening of the fingers obviously is not present, and that of the toes is more apparent than real (Figs. 4 and 5). For the purpose of accurate description, as suggested by Stecher, the condition is properly called brachymetacarpalia and brachymetatarsalia.

Such anomalies have a hereditary basis. Bagg has clearly shown that they are the recessive to the normal in inheritance. Such recessive characteristics can be transmitted in a family for several generations before reappearance; their presence is forgotten during the interval, as in the present case.

The association of the pigmented areas with this anomaly is of interest. Moore has recently emphasized that the skin pigmentations of neurofibromatosis may be associated with bone abnormalities. Twenty years ago, Esau stated that nervous or neurotrophic causes of shortened metacarpals and metatarsals are not excluded, even in the presence of hereditary factors.

Painful feet was the chief complaint in Boorstein's patient, as in the present patient; this is probably due to the altered mechanics of the metatarsal arch. Cotton and Day

FIG. 5

reported a case of bilateral shortening of the fourth metatarsal, without an associated metacarpal shortening, in which the chief complaint was painful feet. Shortening of the metacarpals causes no complaint, other than that of deformity.

The treatment is symptomatic. Limitation of activity was the only method which afforded relief in the present case. If felt pads or leather metatarsal bars are used, alteration from the usual forms must be made, because of the proximally displaced fourth metatarsal heads.

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MULTIPLE OSTEOCHONDRAL BODIES IN THE SYNOVIAL MEMBRANE OF THE KNEE JOINTS IN A CASE OF MIXED RHEUMATOID AND DEGENERATIVE ARTHRITIS

BY JACOB H. TURKELL, M.D., NEW YORK, N. Y.

From the Bellevue Hospital, New York*

Multiple osteocartilaginous bodies of joints occur in greatest number in osteochondromatosis. They may also be of an articular origin, as detached marginal osteophytes in degenerative arthritis, in neurotrophic joints, in osteochondral fractures of joint surfaces, and in osteochondritis dissecans. The following is a case, diagnosed as mixed rheumatoid and degenerative arthritis, in which multiple osteocartilaginous bodies were found embedded in the synovial membrane of both knees.

CASE REPORT

A. G. (No. 216033), a woman, forty-four years of age, was first admitted to the Hospital in April, 1942. The chief complaint was stiff and painful knees, particularly the right knee. Since the age of twenty-two, she had had repeated episodes of arthritis which involved the joints of her hands, elbows, and knees. Clinical examination revealed fusiform swelling of the proximal interphalangeal joints with ulnar deviation of the fingers at the metacarpophalangeal joints. Motion in both elbows and wrists was considerably limited and was associated with thickening of the periarticular structures. Both knees were moderately swollen and were limited in motion, with discrete nodular thickenings palpable in the suprapatellar pouches. Roentgenogram of the right knee, taken at that time, is reproduced in Figure 1.

The diagnosis of rheumatoid arthritis with multiple loose calcified bodies was made, and a synovectomy of the right knee was performed on May 6, 1942. The findings at the operation were reported in part as follows: "The synovium was replaced by a thick fibrous tissue. Above the articular surface of the femur in the quadriceps pouch were many calcified bodies about the size of marbles and joined together by a fatty-looking fibrous tissue."

The pathological report stated: "The specimen consists of bony particles and fibrous tissue; microscopic sections show an inflammatory reaction of round cells, collected in dense aggregations; many of the vessels are invested with loose fibrous tissue and, in several, lymphoid cells are seen cuffing the vessels. Bone spicules and loose fibrous tissue without inflammatory reaction are seen".

The patient was discharged, considerably improved, in June, 1942.

In October, 1943, she re-entered the Hospital because of disabling pain in the left knee. The improved status since operation in her right knee had remained unchanged. Clinical examination of the patient showed both knees to be moderately swollen and, in the suprapatellar pouch of the left, the discrete nodular thickenings described on her previous admission were palpable. None were felt in the right. Examination of heart, lungs, abdomen, and pelvis was normal. Neurological examination disclosed no abnormal findings.

The laboratory report disclosed the following: the sedimentation rate varied from eight to twelve millimeters per hour; blood calcium, phosphorus, and phosphatase levels were normal; uric acid varied from two to four milligrams per 100 cubic centimeters; blood and spinal-fluid Wassermann reactions were negative; and blood count and urine were normal.

FIG. 1

April 15, 1942. Preoperative roentgenogram of the right knee, showing arthritic changes with multiple loose bodies in the synovial membrane of the joint.

* Orthopaedic Service of Arthur Krida, M.D.

FIG. 2-A

April 15, 1943. Showing the ankylosing process of the elbow and the wrist joints. deformity and ulnar deviation are evident.

FIG. 2-B

Destructive changes in the joints of the fingers associated with flexion

On October 27, 1943, a synovectomy of the left knee was performed. The joint was filled with thickened synovia in which were found, in great numbers, calcified bodies, ranging in diameter from one to three centimeters. The consistency of these bodies varied from soft and friable to hard and gritty. The cartilaginous surfaces, particularly of the femoropatellar articulation, showed areas of erosion and hypertrophic changes as evidenced by the formation of peripheral osteophytes. The postoperative course was uneventful.

The pathological report by Dr. Robert J. Poppiti was as follows:

"*Gross Examination:* The gross specimen consisted of numerous irregular masses that varied from one to three and one-half centimeters in diameter. All were either completely or partially enveloped by the thickened, ragged, yellowish-gray synovium. They varied in consistency, being hard in some areas, and soft in others. The masses consisted of material resembling bone, cartilage, and fibrous tissue.

"*Histological Examination:* A section through one of the larger masses shows it to be composed of a central core of well-formed bone with fat between the bony trabeculae. Along the surfaces of some of the trabeculae are prominent osteoblasts. At the peripheral surface, the bone in a few places is covered with cartilage that is undergoing ossification. The mass of bone is surrounded by a capsule of connective tissue of varying density and width; in it are small islands of well-formed cartilage and an occasional small mass of osteoid. Continuous with this capsule is a long strip of fibrocartilage. The capsule surrounding the bone contains large groups of lymphocytes usually in the vicinity of small blood vessels; on the surface is a layer of prominent columnar cells. Section of another mass reveals it to be of essentially the same composition. Attached to this mass are several finger-like projections of fibrous tissue, densely infiltrated with lymphocytes and covered with columnar cells. A third mass is composed of fat and connective tissue; it is moderately vascular and contains scattered aggregates of lymphocytes and plasma cells. Another one of the masses has a center of bone, with fat between the trabeculae. Small islands of cartilage at the periphery of the bone are being calcified and transformed into bone. The surrounding capsule of connective tissue is moderately vascular and contains pockets of lymphocytes near blood vessels. Slender projections of connective tissue extend from the surface; these are the site of chronic inflammatory reaction and are covered with one or more layers of columnar cells." (See Figures 4, 5, and 6.)

The slides of the tissue removed from the right knee (May 6, 1942) were reviewed. No masses of osteoid tissue, similar to that shown in Figure 6, could be found in the slides available for study.

DISCUSSION

The presence of osteochondral bodies in the synovial membrane of both knees to such an extent as to simulate osteochondromatosis is certainly an unusual feature when occurring in joints which are the seat of rheumatoid and degenerative changes.

FIG. 3-A

FIG. 3-B

April 15, 1943. Preoperative roentgenograms, showing atrophic arthritic changes of the left knee, with multiple loose bodies of the osteochondromatous type and hypertrophic changes, particularly of the femoropatellar articulation.

Secondary neuropathic derangement superimposed upon a chronic long-standing rheumatoid and degenerative arthritis might conceivably have given rise to the picture presented. This, however, may be ruled out by the absence of abnormal neurological findings and the negative blood and spinal-fluid Wassermann reactions.

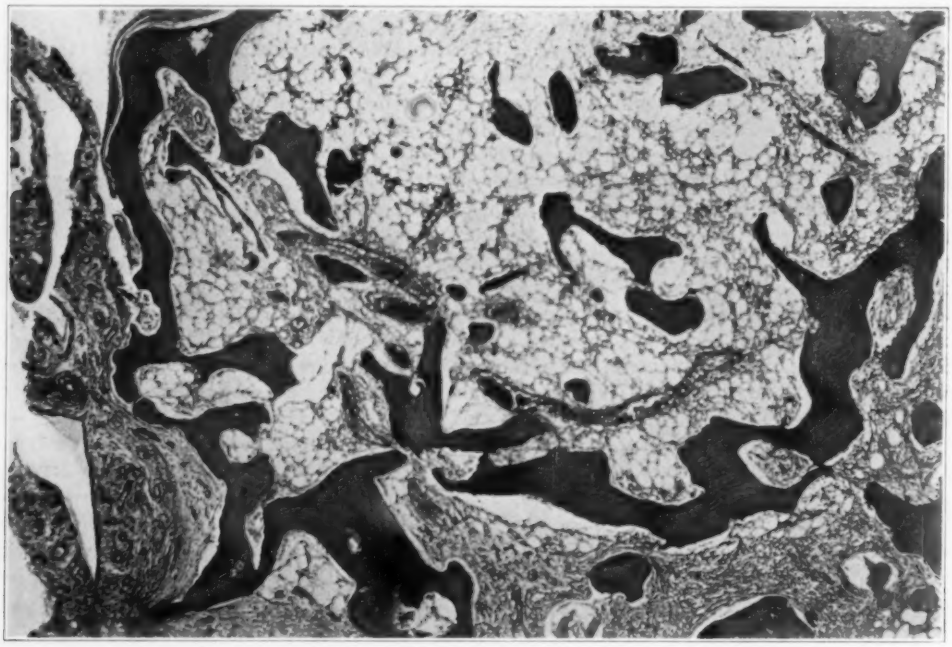

FIG. 4

Photomicrograph (×20), showing an osseous body, containing adult bone spicules with fatty marrow surrounded by chronic granulation tissue, within the synovial membrane.

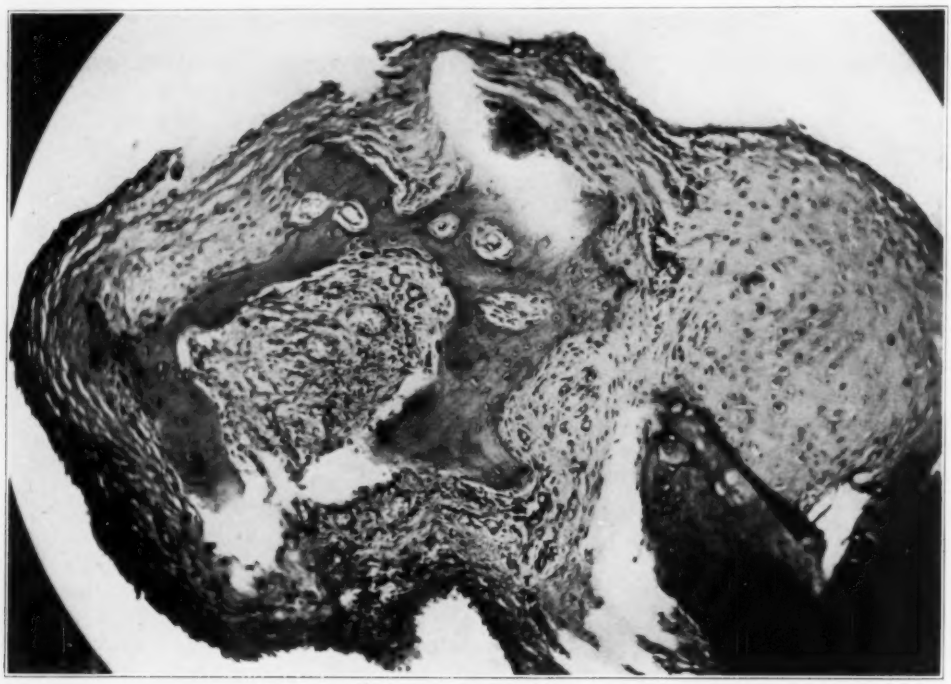

FIG. 5

Photomicrograph (×72), showing an island of well-formed cartilage and bone spicules within a synovial villus. Along the surfaces of the bone, osteoblasts are prominent.

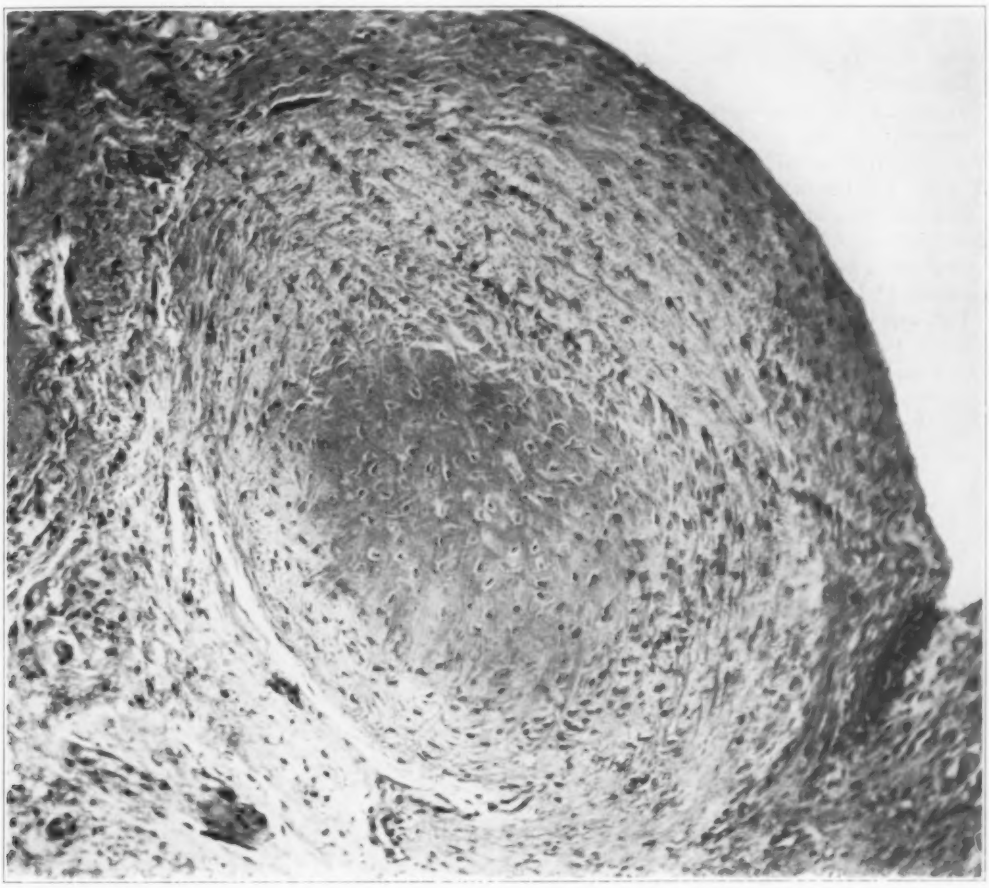

FIG. 6

Photomicrograph (×110), showing an area of osteoid tissue in a chronically inflamed synovial villus, indicating osteoid metaplasia of the synovial membrane.

That the case may be one of osteochondromatosis in a chronic rheumatoid arthritis might also be considered. Opposed to this are the involvement of both knees, the histological evidence of a chronic synovitis, and the absence of nests of embryonal cartilage cells in various stages of transformation to the more mature type, which would indicate that the changes seen in the synovial membrane are most probably due to an inflammatory, rather than to a neoplastic or developmental process.

It is further conceivable that these bodies arose from peripheral osteophytes which became detached and then secondarily embedded in the synovial membrane. Yet it is difficult on this basis alone to account for the large number of bodies present, the absence of any dead bone or amorphous marrow in the core of at least some of the bodies, and, particularly, the histological evidence of isolated areas suggestive of osseous metaplasia in the villi of the chronically inflamed synovial membrane (Fig. 6).

There is also the possibility that these bodies may have arisen by direct metaplasia of the chronic granulation tissue. The paucity of areas of osseous metaplasia found on histological examination and the failure to note nests of cartilage cells of the more embryonal type, with subsequent maturation and ossification, does not particularly favor such a concept. However, in the chronically inflamed synovial membrane appear areas of osteoid tissue (Fig. 6), together with islands of well-formed cartilage and bone spicules, the surfaces of the latter lined by osteoblasts (Fig. 5).

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A TREATMENT FOR DISPLACED FRACTURES OF THE PELVIS

BY CAPTAIN CAROLL M. SILVER AND MAJOR HAROLD W. RUSBRIDGE

Medical Corps, Army of the United States

Many methods have been employed in the treatment of fractures of the pelvis. In 1935, Jahss reported an ingenious technique which was both simple and effective. The lower extremities were encased in individual long-leg plaster casts, and two turnbuckles were incorporated between them, one, transversely between the thighs, and the other, between the ankle portions of the casts. This created a trapezoid with rigid sides and movable horizontal bars. The lower extremities thus became functional levers. By opening the upper turnbuckle and closing the lower one, a powerful horizontal distracting force could be applied to the pelvis through the medium of the ligaments of the hip joints. Overriding fractures of the ischial and pubic rami, or fractures of the acetabulum with intrapelvic protrusion of the femoral head, could be reduced readily by this method. In the case of a distraction injury of the pelvis, such as a separation of the symphysis pubis, a compression force to effect reduction was applied to the pelvis by closing the upper turnbuckle and opening the lower one.

A patient with an overriding unilateral fracture of the pubic and ischial rami was admitted to a station hospital in North Africa, and it was planned to treat the pelvic fractures by the Jahss method. Since turnbuckles were unobtainable, a simple substitute was necessary. This case report is presented as a practical suggestion for the treatment of pelvic fractures, and may be of particular use in military hospitals overseas where nonstandard equipment must often be improvised or a substitute found.

CASE REPORT

J. T., a Navy lieutenant, thirty-six years of age, was admitted to a station hospital in North Africa, April 16, 1943, shortly after he had been thrown from a jeep which overturned while in motion. The patient was in moderate shock, and an intravenous infusion of 1000 cubic centimeters of plasma was begun at once. Examination revealed a severe laceration of the right scrotal sac, with protrusion of the right testicle through

the wound. Marked tenderness over the left pubic and ischial rami was found, and lateral compression of the pelvis caused severe pain in this region. A tentative diagnosis of fracture of the pelvis was made. The patient was catheterized soon after admission; clear yellow urine was obtained. Several hours later, a roentgenogram of the pelvis was made, which revealed fractures of the left superior pubic and ischial rami with moderate overriding of the fragments (Fig. 1). Padded plaster-of-Paris circular casings were applied to each lower extremity from the upper thigh to the ankle, with the knees in full extension. A pad of felt, three-quarters of an inch in thickness, was applied about the upper thighs, the knees, and the ankles before the legs were encased in plaster. The scrotal laceration was cleaned thoroughly with normal saline, the testicle was replaced in the scrotal sac, sulfanilamide powder was sprinkled into the scrotum, and the laceration was repaired with interrupted black-silk sutures. Two days later, when the casts were dry and firm, the patient was placed on the x-ray table in the supine position. He had been given a quarter of a grain of morphine half an hour earlier. A wood block, six inches wide and two inches thick, was placed transversely between the upper-thigh portions of the plaster cylinders, and a webbed canvas strap with a buckle was placed around the

FIG. 1

Prereduction roentgenogram showing overriding fractures of the left pubic and ischial rami.

FIG. 2

The block of wood and the webbed strap are in position. The patient is lying on the x-ray table.

FIG. 3

The wood block and the strap have been incorporated in plaster-of-Paris following reduction, to ensure fixation of the reduced fragments.

FIG. 4

Postreduction roentgenogram. There is normal alignment of the left pubic and ischial rami.

ankles (Fig. 2). The webbed strap was tightened, producing a horizontal distraction force on the pelvis by levering the lower extremities over the block fulcrum. When the patient complained of moderate pain at the fracture site, the tightening of the strap was stopped, and a roentgenogram of the pelvis was made. The postreduction roentgenogram showed complete correction of the overriding with normal alignment of the fracture fragments. The wood block and webbed strap were incorporated in the plaster-of-Paris casts to ensure fixation of the reduced fragments (Fig. 3), and the patient was returned to the ward.

It had been almost impossible to place the patient on a bedpan, because of the severe pain prior to the final fixation of the plaster casts. Following immobilization in the casts, the patient could be lifted on a bedpan or could be turned with ease, and he was able to sit up in bed or in a wheelchair without difficulty. A roentgenogram taken several days later showed no change in the anatomical alignment at the fracture sites (Fig. 4). The scrotal wound healed *per primam* and the sutures were removed after one week. On April 28, 1943 the patient was transferred to a Naval Dispensary in accordance with orders from Headquarters and no further record has been obtained regarding the case. At the time of transfer, the officer was quite comfortable and was out of bed daily in a wheelchair.

COMMENT

The materials required for reduction and immobilization of pelvic fractures are few and easily obtainable. They include plaster-of-Paris, sheet wadding, felt, a block of wood, and a webbed strap or ordinary trousers belt. For a distraction fracture or pubic symphysis separation, the block of wood and webbed strap are simply reversed. Morphine sedation was adequate in this instance for the reduction procedure. The obturator muscles and pelvic ligaments act as automatic aids to check the possibility of overdistraction in the reduction of overriding fractures. In a second article in 1939, Jahss advised the use of two turnbuckles between the thighs to prevent external rotation of the limbs. The authors made no special attempt to prevent the external rotation of the lower extremities, since the transverse distracting force was not affected. In fact, a slight amount of external rotation is desirable, since it reduces the amount of direct stress on the lateral ligaments of the knee, caused by the leverage action of the reduction mechanism.

The patient is surprisingly comfortable in the retention casts after the initial postoperative reaction, and he can be turned over or propped up in bed; he can be placed on a bedpan, or can be put in a wheelchair. Of great importance in wartime is the fact that the patient can be transported with safety to a base hospital or other rear echelon installation. Associated wounds of the pelvic region can be treated with ease, since only the lower extremities are enclosed in the casts.

If the pelvic fracture is complicated by displacement in the vertical axis, the incorporation of a Roger Anderson well-leg apparatus in the casts for vertical traction, as reported by Jewett, would be advisable.

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RAPID ROENTGENOGRAPHY IN THE OPERATING ROOM

BY W. L. MINEAR, M.D., PH.D., MEMPHIS, TENNESSEE

From the Willis C. Campbell Clinic, Memphis

The purpose of rapid roentgenography in the operating room is to save anaesthetic time, especially in patients who are poor risks, and to facilitate the developing of roentgenograms in hospitals where the dark room is remotely or inconveniently placed. The problem of rapid roentgenography has been discussed by Ollerenshaw, who used a special single-solution developer in a portable box. The formula was unique in that it contained hypo mixed with developer in a highly alkaline solution, and fixation proceeded at the same time as development. This caused a tendency to reduce film density, and it was, therefore, necessary to double the normal exposure time. The chemicals were mixed immediately before being used, and, because of instability, were discarded after one use. The solution was contained in a developing tray, placed in the bottom of the portable box. The cassette was unloaded in the light-tight box, and the film was developed for forty-five seconds, when it was ready for inspection by the surgeon. The film was then immersed in hypo, as in the standard procedure when permanent films are desired. F. R. Wilkinson modified Ollerenshaw's solution and discussed its use.

Our experience with the single-solution developer revealed its advantages of speed and simplicity. Its disadvantages were a low-density film with yellow discoloration (fog), and non-diagnostic lateral hip films in heavy subjects. The solution is unstable, can be used only once, and costs approximately fifty cents per 1000 cubic centimeters.

It was found that the quality of the films could be improved to some extent, with less fog, if the films were immersed in hypo for five to ten seconds after developing. The roentgenograms of extremities and hips in thin subjects were considered diagnostic, and were of fair quality; however, continued difficulty was experienced in visualizing the head and neck of the femur in the lateral exposure in heavy subjects (curved cassettes were used). Because of these difficulties, the single-solution developer was discarded in favor of a fast, concentrated, commercial liquid developer* which was used warm or at room temperature, with the standard procedure of successive immersion in developer, wash water, and hypo. This procedure was carried out in a light-tight portable box in which was installed a standard dental tank, large enough to hold films eight by ten inches in size. Films are developed one minute, at 85 degrees Fahrenheit, are rinsed, and are placed in hypo for thirty seconds. It was found that one and one-half to two minutes for the whole procedure was rapid enough for all practical purposes, and films of good quality were obtained. The time-temperature factors for fresh developer are: one and three-quarters minutes at 75 degrees Fahrenheit, one and one-quarter minutes at 80 degrees Fahrenheit, one minute at 85 degrees Fahrenheit, and forty-five seconds at 95 degrees Fahrenheit. About forty-five films, eight by ten inches, may be developed in three-fourths of a gallon of developer before any lessening of film density will be noticed. The rate of oxidation of developer doubles for each 10-degree rise in temperature over 65 degrees Fahrenheit. The higher the concentration of developer, the more rapid is the oxidation.

The developing solution can be warmed to the desired temperature immediately before it is used, or it may be kept at a constant temperature while in use by a special thermostatically controlled heating unit immersed in the developing solution. Construction of the portable box, placement of the cassette and tank, and the nature of the film holders are illustrated in Figures 1 and 2.

* The time factors mentioned are based on the use of "Supermix developer" and "hypo" (General Electric), used in dilution recommended.

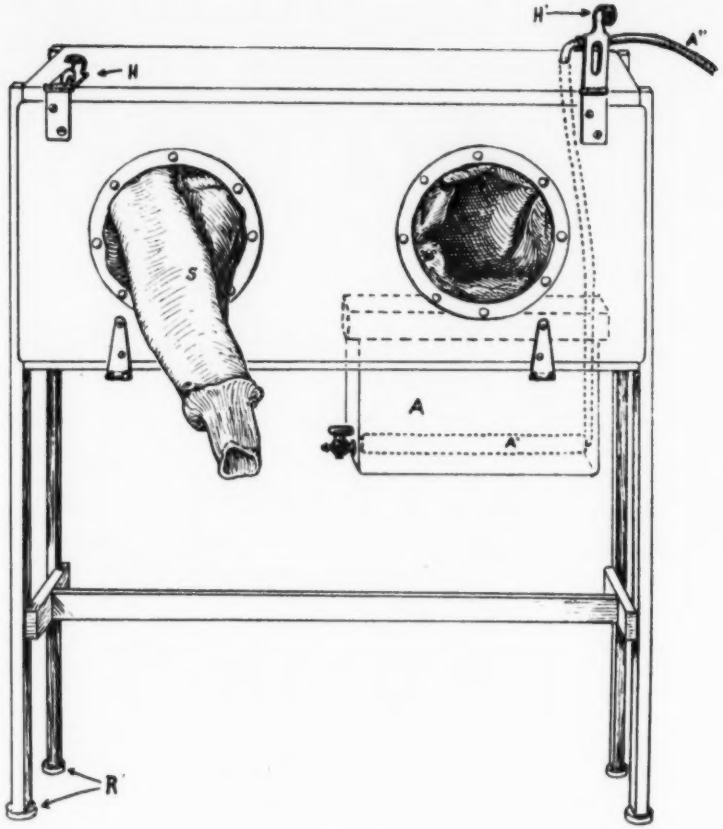

FIG. 1

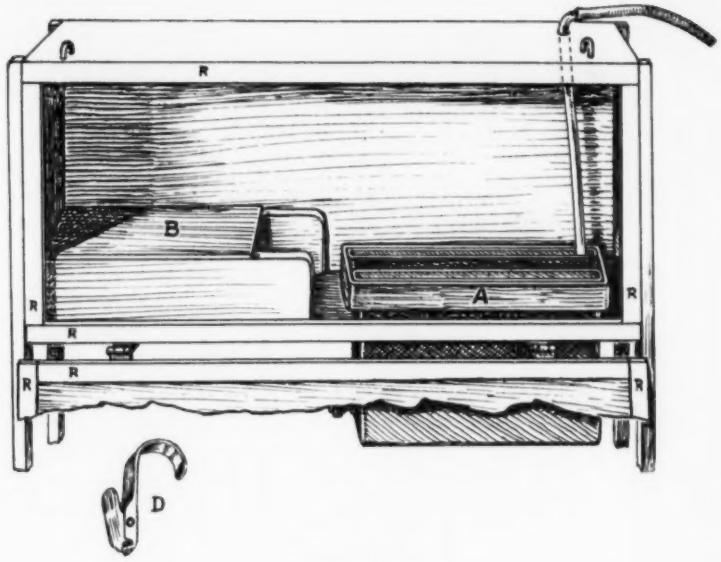

FIG. 2

Figs. 1 and 2: The portable box, of plywood, is made with light-tight seams. Inside dimensions are: thirty inches in length, fifteen inches in height, and twelve inches in width. The door has two armholes, eight inches in diameter and four inches apart, with attached rubber-sheeting sleeves (*S*) (everted on left, Fig. 1), and stockinette cuffs (four thicknesses). The sleeves are attached by means of stove bolts with plywood rings and felt gaskets. The opposing edges of the door and box have sponge-rubber strips, one inch wide and a quarter of an inch thick. The door is attached with hinges and is secured when closed with a common latch (*H* and *H'*). The box is supported by legs twenty-six inches high, so that the technician may conveniently sit down while developing films. Rubber tips (*R'*) are placed on the legs to prevent slipping of the box on the floor. The interior of the box has a small elevated cassette platform (*B*) on the left. The area under the cassette platform is lined with lead foil, one millimeter in thickness, and is used for storing films. A standard dental tank (*A*) (7¼ by 13¼ by 9¾ inches, outside diameter) is shown on the right. A thin rubber strip around the opening in the bottom of the box makes the tank installation light-proof. Placement of the thermostatically controlled heating unit (*A'*), in the rear compartment containing developer, and of the cord (*A''*) leading to current of 110 volts is shown. The stopcock at the bottom of the tank drains the wash water after each use. A constant flow of wash water is optional. The developing and hypo tanks may be removed for change of solutions. Dental clip for holding film is shown in Figure 2 (*D*).

The portable dark room should be conveniently placed near the x-ray view box in the operating room. The temperature of the warm developing solution should be measured, and the developing time should be predetermined by reference to the time-temperature table. Roentgenograms are taken with the portable x-ray unit; the operator follows standard technique for the part. The developing time need not be increased, but this is left to the discretion of the technician. Our technique for lateral hip roentgenograms involves the use of a curved cassette placed between the legs. The anteroposterior view is taken with a flat cassette with attached Siemen's grid, and is placed in an x-ray tunnel centered under the patient's hips. The curved cassette is placed on top of the flat cassette on the left side of the box. The lid is closed, and the technician inserts his hands and arms in the light-proof sleeves attached to the portholes; both hands are used to unload the curved cassette. The film is held with the left hand, and the film holder, which is kept in the box, is grasped in the right hand; the film is then attached. The film is placed in the developing solution in the back compartment of the tank. This procedure is repeated for the anteroposterior film in the flat cassette. The two films remain in the developer for the proper length of time (for example, one minute at a temperature of 85 degrees Fahrenheit), are rinsed briefly in water in the center tank, and then are placed in hypo contained in the front compartment. The technician now may withdraw his hands and open the lid of the box. Ideally the films should be left in the hypo as long as the developing time, but they may be withdrawn from the box in thirty seconds and placed on the view box for inspection. If permanent films are desired, they should be reimmersed in hypo, and washed and dried in the usual manner.

The cassettes may be loaded in the box as follows: A box of film, eight by ten inches, is placed flat on the cassette platform (Fig. 2, *B*), so that the lid may be removed toward the right. The unlocked flat cassette opening to the right is placed on the box of film, and the unlocked curved cassette, in turn, is placed on the flat cassette. The portable box is now closed, and the technician inserts his arms in the sleeves. The lid from the film box is removed and is placed under the cassette platform. Cassettes are opened individually with the left hand, and the film is inserted with the right hand. Cassettes are then locked, using both hands, and the lid to the film box is replaced. Films are stored under the cassette platform between loadings.

The solutions are stable, and can be kept in the tank or stored in gallon bottles. Wash water should be drained after each use. The tank can be easily lifted out of the box, or the developing and hypo compartments within the tank may be lifted out separately and cleaned.

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A CASE OF CYST OF THE SACRUM WITH NO INCREASE AFTER THIRTY YEARS

BY JOEL E. GOLDTHWAIT, M.D., BOSTON, MASSACHUSETTS

On March 18, 1920, a case was reported in the *Boston Medical and Surgical Journal*, entitled "A Case of Tumor of the Sacrum". This report is now given, since it seems of distinct value to know something of what happens in these cases.

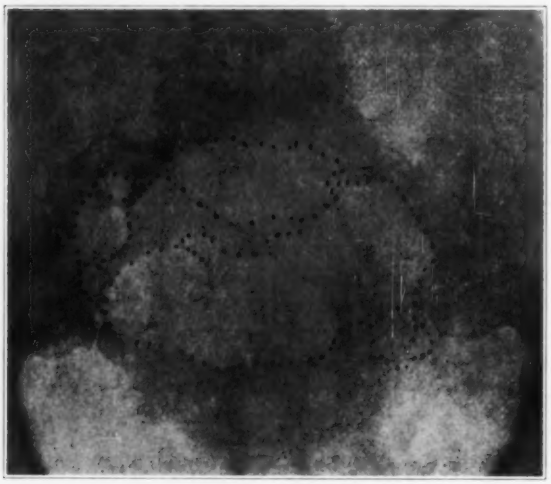

FIG. 1

Reproduced from Boston Medical and Surgical Journal by courtesy of The New England Journal of Medicine.

At the time the case was first reported, the patient, a woman, was forty-four years of age. She had been referred to me in November 1909 by Dr. Maurice H. Richardson, who sent the following letter:

"She was operated upon by a friend of mine, Dr. Giles, of Hanover, N. H. Dr. Giles some years ago did a ventral fixation. It was thought at that time that she had some malignant disease of the liver. I studied her case carefully and then operated, finding that the ventral fixation had become separated and that there were gall-stones. I removed the gall-stones and fixed up the uterus. In the hollow of the sacrum there was a mass which I supposed to be inflammatory before operation. Inside the abdomen I found a firm mass connected with the sacrum, sessile, broad, and evidently containing fluid. We thought at the time that this might be due to caries of the sacrum. She has

FIG. 2

January 19, 1933.

FIG. 3
June 2, 1944.

done very well indeed since the operation. She is the picture of health. The mass in the hollow of the sacrum is distinctly smaller, but on the posterior surface of the sacrum there is, as you will see, a prominence which confirms the diagnosis of caries of a benign origin."

At the time of the examination, there was a marked prominence of the upper part of the sacrum, giving the impression at first of a distinct spondylolisthesis; but, on more careful investigation, it was evident that the whole spine had not been displaced forward, as it is in spondylolisthesis, but that much of the appearance suggestive of this condition was due to the swelling over the sacrum, associated with a considerable forward inclination of the pelvis. The roentgenogram taken at that time (Fig. 1) showed an almost complete destruction of the sacrum; only a shell remained around the outer edges, so that there could not have been more than one-half of an inch of bony structure in contact with the ilia. The same was true of the upper part of the sacrum, upon which the spine would naturally rest.

The condition was so extensive that operative treatment was considered inadvisable, and a support was arranged to protect the pelvis and the low back. The patient was relieved of the discomfort, for which treatment was sought, and, for many years, has been an active person, carrying on a drug-store business of her own.

Since the report presented previously, the patient has been seen by me occasionally. After a somewhat longer interval she was seen again. At that time, she had given up her business, but was doing her housework, moving about a moderate amount, having very little pain, and being in remarkably good condition for her age, which was seventy-nine years. The roentgenograms which were taken at that time (Fig. 3) showed a condition almost exactly like that which was shown at the time of the first examination in 1909.

The case, of course, represents a cyst of the sacrum, with marked destruction of the main part of the bone, which has remained for many years entirely inactive.

MARCH FRACTURE OF THE NECK OF THE FEMUR

A Case Report

BY MAJOR MURRAY E. GIBBENS

Medical Corps, Army of the United States

In view of the present interest in march ("insufficiency", "fatigue") fractures, the author submits herewith a report of a case of march fracture of the neck of the femur, similar to those reported by Branch, Mullard, and Watson and Berkman.

The patient, a white male, thirty-eight years old, was brought to the Orthopaedic Section of the Station Hospital, Camp Barkeley, Texas, on January 7, 1943. He was a man of rather asthenic build, and prior to induction he had been a dentist. He had experienced sudden, severe pain in his right hip during a twenty-five mile march, and was unable to bear weight on his right leg. There was no history of injury or unusual strain, other than that of walking. He had not fallen, and he could not recall having stumbled or having turned his ankle. He had had no similar attacks of pain previously. There was some muscle spasm on rotation of the right hip; otherwise there was no limitation of motion except upon sudden extension. The diagnosis on admission was acute arthritis of the right hip.

Roentgenographic examination

A series of roentgenograms was taken, and the final diagnosis of march fracture of the neck of the femur was made.

The first x-ray (January 8, 1943) yielded "negative" findings. However, on minute scrutiny, it was subsequently found that there was a break in the continuity of the cortical surface of the inferior margin of the femoral neck (Fig. 1), which appeared as a very small, oblique, linear defect in the cortex. No similar break could be found in the superior margin of the neck.

On January 29, 1943, the second roentgenogram was taken, and the following report was made: "There is definite evidence of a fracture through the neck of the right femur, with discontinuity of the cortical borders in each side, and a line of decreased density extending across the neck, bordered by an increase in density on each side. The line of the neck and head of the femur has not been altered. We believe this is a march fracture of the neck of the right femur".

A third x-ray, under date of February 20, 1943 (Fig. 2), showed that, "There is now some bone condensation about the previously described fracture line across the neck of the right femur".

The report after roentgenographic examination on April 5, 1943, stated: "There is obliteration of the previously reported fracture line, with visible callus on the medial side of the neck of the right femur".

Treatment consisted of bed rest, with motion allowed in bed. On January 14, exercises in bed were started, and the patient was permitted to be up on crutches for short periods of time, without weight-bearing on the right leg. A week later, he had good, active motion in the right hip. Weight-bearing was not allowed until one month after admission, at which time he began to walk with a cane.

On March 12, 1943, the patient was placed on temporary "limited service" status for a period of six months. This was chiefly because of his age and the type of injury.

This soldier returned to duty from the Hospital on March 19, 1943, and was able to complete his basic training without difficulty.

Follow-up examination was made at the Orthopaedic Clinic on May 5, 1943. A roentgenogram taken at that time (Fig. 3) showed good healing, with a moderate amount of callus at the fracture site. The hip joint functioned normally, and the patient walked without difficulty.

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FIG. 3

May 5, 1943. Increased density is visible at the fracture site, with callus at the medial side of the femoral neck.

FIG. 2

February 20, 1943. Between the two arrows is the area of bone condensation.

FIG. 1

January 8, 1943. The lower arrow indicates the site of the break in the continuity of the cortex on the inferior surface.

BILATERAL CONGENITAL CALCANEOCUBOID SYNOSTOSIS

A Case Report

BY CAPTAIN HOWARD W. MAHAFFEY

Medical Corps, Army of the United States

From the Orthopaedic Service, A.A.F. Regional Station Hospital, Truax Field, Madison, Wisconsin

Congenital synostosis of the tarsal bones appears to be a rare deformity, since only a few cases have been reported in the literature. Congenital fusion of the calcaneocuboid joint in the foot, without either synostosis or absence of other tarsal or metatarsal bones, has been reported by Wagoner, and Bargellini. Wagoner's patient was a boy, nine years of age, who had pain in both feet on arising, with relief following exercise. Lapidus reviewed the literature on congenital fusion of the foot bones and described a case of talonavicular synostosis. O'Donoghue and Sell have reported another case of congenital talonavicular synostosis.

The tarsal cartilages appear in the embryo of about fourteen millimeters, and the joint cavities develop in the embryo twenty-five to thirty millimeters long. It is at this later period, when the foetus is approximately two months old, that there is a failure of the joint cavity to develop, and the two bones grow as one.

CASE REPORT

A white male, thirty-five years of age, was seen in the Orthopaedic Clinic of the Station Hospital, Truax Field, with the complaint of back pain. He had sustained a fracture of the right lateral malleolus four years previously, and had felt pain on walking on the right foot since that time. There were no complaints referable to the left foot. Examination of the feet showed bilateral pes planus of 2 degrees. Dorsiflexion was limited, as were eversion and inversion of both feet. A roentgenogram of the right foot was ordered, and, when structural changes were found, one of the left foot was taken for comparison.

The roentgenogram of the right foot (Fig. 1-A) showed no joint space between the calcaneus and the cuboid. These bones appeared otherwise normal. The subtalar joint was normal. On the posterior surface of the talus was a mass of bone which measured one by one centimeters. A mass of similar size and appearance was present on the anterior superior surface, just posterior to the talonavicular joint. The roentgenogram of the left foot (Fig. 1-B) showed it to be similar to the right, except that there were hypertrophic changes at the cuneonavicular articulation. Since there was no history of severe trauma or infection in either foot, and the identical lesion was found bilaterally, a diagnosis of bilateral congenital calcaneocuboid synostosis was made.

DISCUSSION

As motion in the calcaneocuboid joint is prohibited in this condition, there is a strain on the other intertarsal joints, and an anomaly of this type is likely to be symptomatic. The hypertrophic changes in the left foot in this case are probably the result of this strain. As a therapeutic measure, a subtalar and talonavicular arthrodesis might prevent such a strain on the other intertarsal joints and relieve symptoms. This was not attempted in this case because of military policy.

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FIG. 1-B

Roentgenogram of the left foot, showing calcaneocuboid synostosis.

FIG. 1-A

Roentgenogram of the right foot, showing calcaneocuboid synostosis.

V PLASTER SPLINT FOR MAINTAINING REDUCTION OF CONGENITAL DISLOCATION OF THE HIP

BY R. PLATO SCHWARTZ, M.D., ROCHESTER, NEW YORK

The purpose of this brief illustrated report is to reveal the advantages of departure from the conventional plaster spica for immobilization of congenital dislocation of the hip.

On March 29, 1944, when the patient, (J. F.) was two years of age, a closed reduction of bilateral congenital dislocation of the hip was performed, with fixation in a conventional plaster spica.

On April 14, 1944, the patient was discharged to her home.

On April 26, 1944, she was readmitted, because the spica was saturated with urine, and there was cutaneous inflammation over the pelvic area and the proximal third of both thighs. The inflammation cleared up within two weeks following the removal of the spica. Recurrence of bilateral dislocation (Fig. 1-A) made a second reduction necessary.

On May 9, 1944, closed reduction of both hips was again done; fixation was obtained by a V plaster splint (Figs. 2-A and 2-B). Roentgenograms showed that the reduction had been maintained (Fig. 1-B) by this V splint when patient was sitting up (Fig. 1-C).

On August 18, 1944, the patient was readmitted. The plaster was unsoiled, but tight from increased growth of the patient. New plaster was applied without anaesthesia (Fig. 1-D).

The roentgenograms indicate that reduction of both hips has been maintained in two successive V plasters. It is now nearly six months since the first one was applied to this patient. During that time, the patient has been free to sit up, and the reduction has remained unchanged.

FIG. 1

A. Bilateral dislocation before reduction.
B. Closed reduction maintained by V plaster splint.
C. Reduction maintained, patient sitting up (Compare with Fig. 2-A).
D. Reduction maintained by second V plaster splint (Note the difference in the acetabula by comparing *A* and *D*).

FIG. 2-A

FIG. 2-B

FIG. 2-C

V plaster splint for congenital dislocation of the hip. No special precautions are required for assuring cleanliness. From the prone position, the patient can sit up with ease.

The plaster has remained dry and clean, without the hours of work or special devices necessary to prevent soiling, as is required when a conventional spica is used.

The freedom of rotation of the pelvis on the fixed femoral heads is a normal function of the hip joints. This cannot be exercised in the conventional spica, while complete immobility contributes to atrophy and contraction. The influence of motion on the more rapid development of the acetabular shelf and stability must await evaluation.

Maintenance of reduction, some freedom of hip function, and cleanliness without effort are the present reasons for using the V splint in preference to the conventional plaster spica.

AN EXTENSION DRILL POINT WITH A PROTECTING SLEEVE FOR USE IN BONE AND JOINT SURGERY

BY MAJOR LOUIS W. BRECK

Medical Corps, Army of the United States

In certain operative procedures, notably the Nicola operation for recurrent dislocation of the shoulder, technical difficulties arise in placing a hole through a bone largely because the hole is nearly parallel to the long axis of the bone. In an attempt to facilitate the drilling of such holes, the author has devised a drill point with an extension on it and with a tubelike sleeve over it. The motor-driven drill is superior to the hand drill for use with the apparatus described in this article.

The extension drill with sleeve is very simple in construction, and can be made at little cost. A piece of drill rod, or other suitable steel rod, twenty-one centimeters (9 inches) long, is brazed onto an ordinary drill point of the desired size (Fig. 1). The extension should be slightly smaller than the drill point. Brazing is preferred to welding, because the bond which it produces is less apt to fracture. The joint is made smooth and of the same size as the extension rod.

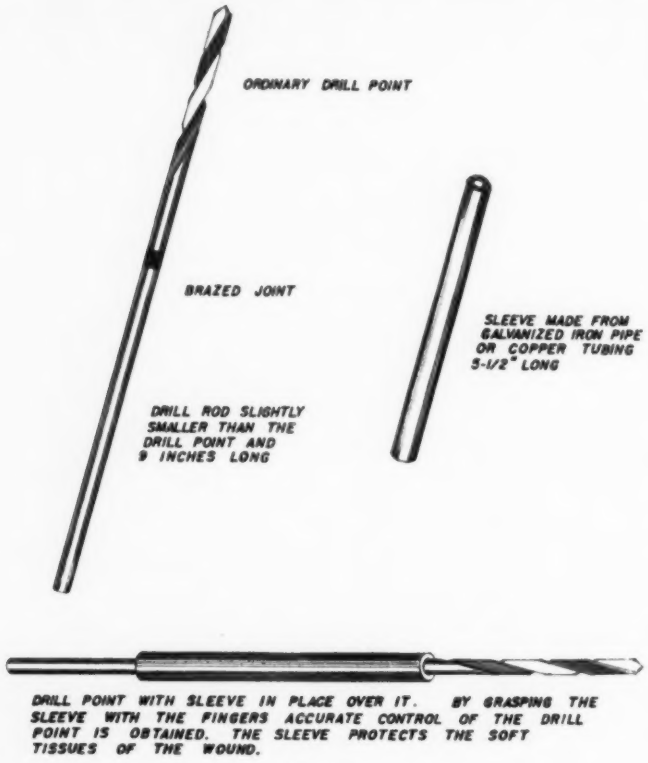

ORDINARY DRILL POINT
BRAZED JOINT
SLEEVE MADE FROM GALVANIZED IRON PIPE OR COPPER TUBING 5-1/2" LONG
DRILL ROD SLIGHTLY SMALLER THAN THE DRILL POINT AND 9 INCHES LONG
DRILL POINT WITH SLEEVE IN PLACE OVER IT. BY GRASPING THE SLEEVE WITH THE FINGERS ACCURATE CONTROL OF THE DRILL POINT IS OBTAINED. THE SLEEVE PROTECTS THE SOFT TISSUES OF THE WOUND.

FIG. 1

The sleeve for the larger sizes of drill points is made from a piece of galvanized cast-iron pipe, 13.75 centimeters (5½ inches) long, with a bore 0.3 of a centimeter (⅛ of an inch) in diameter. Copper tubing is used for smaller drill points. The ends of the sleeve are carefully reamed out to the full size of the pipe or tubing, and they are smoothed with a file or emery cloth. A close fit between the drill point and the sleeve is not desirable; a quite loose fit works well, and makes it possible to use one sleeve for several sizes of drill points.

In drilling holes nearly parallel with the axis of the bone, four main difficulties are encountered.

In the types of motor drills more commonly used (excluding the cable-drive type), the motor will not lie flat enough against the extremity, so that the hole can be properly directed. The long drill point overcomes this by allowing the motor to be placed so far from the incision that it can be held close to the patient, thus making almost any angle possible.

When the drill point rests on the soft tissues at the end of the wound from which the hole is being drilled, the tissues are badly traumatized. The sleeve completely shields the soft tissues from the drill point, because the latter runs inside the sleeve and the sleeve does not turn.

In drilling holes at an acute angle, the tip of the drill point frequently skids about, when the hole is being started. This can be overcome very easily with the extension drill with sleeve, by grasping the sleeve firmly and holding the drill point in the desired place.

The fourth difficulty is that the drill point is sometimes too short to go through the bone. This is overcome by the long extension on the drill point.

It has been found that the extension drill with sleeve is of great value in drilling holes in bone at odd angles, particularly the hole required in the Nicola operation. It facilitates the drilling, saves operating time, reduces trauma to the soft tissues, aids in the accurate placing of the hole, and obviates the danger of the drapes catching on the drill point and becoming wound around it.

News Notes

THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

By unanimous vote of its Executive Committee, The American Academy of Orthopaedic Surgeons has postponed to an indefinite date the Thirteenth Annual Convention, which was scheduled to be held in Chicago, January 21 to 24, 1945. This action was taken in compliance with the request of the Office of Defense Transportation.

The Fellows of the Academy elected during the past year are the following:

Dr. Alexander Philip Aitken, Boston, Massachusetts.
Dr. Harry B. Allison, Tacoma, Washington.
Dr. Alvin M. Arkin, New York, N. Y.
*Dr. Sam W. Banks, Chicago, Illinois.
Dr. William P. Bartels, Garden City, New York.
Dr. Clarence W. Betzner, Cincinnati, Ohio.
Dr. Donald W. Blanche, South Pasadena, California.
Dr. Henry Briggs, East Orange, New Jersey.
Dr. Brandon Carrell, Dallas, Texas.
*Dr. Francis J. Cox, New Orleans, Louisiana.
*Dr. Anthony F. De Palma, Newark, New Jersey.
Dr. Douglas D. Dickson, Oakland, California.
*Dr. Kerwin Armand Fischer, Louisville, Kentucky.
*Dr. John D. B. Galloway, Minneapolis, Minnesota.
*Dr. J. Neill Garber, Camp Bowie, Texas.
Dr. Harold W. Gehring, Detroit, Michigan.
*Dr. Everett Moore George, Des Moines, Iowa.
*Dr. David Goldberg, New York, N. Y.
*Dr. James William Graham, Sioux City, Iowa.
*Dr. Walter C. Graham, Santa Barbara, California.
*Dr. Ronald S. Haines, Phoenix, Arizona.
Dr. Bernard Mark Halbstein, Long Branch, New Jersey.
Dr. Delbert Hand, San Francisco, California.
*Dr. Charles U. Hauser, Cincinnati, Ohio.
Dr. George Washington Holmes, Winston-Salem, North Carolina.
*Dr. J. Howard Johnson, Milwaukee, Wisconsin.
*Dr. Robert W. King, Pasadena, California.
*Dr. Earl S. Leimbacher, Joliet, Illinois.
*Dr. Irwin Snyder Leinbach, Reading, Pennsylvania.
*Dr. Allen S. Lloyd, Washington, D. C.
Dr. Ian MacKenzie, Tulsa, Oklahoma.
Dr. Ira O. McLemore, Seattle, Washington.
Dr. Arthur A. Michele, New York, N. Y.
*Dr. Abraham Myers, Philadelphia, Pennsylvania.
Dr. Lawrence Noall, Portland, Oregon.
Dr. Maurice F. O'Connell, Hartford, Connecticut.
*Dr. Darrell O. Overpeck, Fresno, California.
*Dr. Edward Parnall, Denver, Colorado.
Dr. Fred A. Polesky, Los Angeles, California.
Dr. M. John Rowe, Jr., Long Beach, California.
*Dr. F. I. Schwartzberg, Paterson, New Jersey.
Dr. James W. Shumate, San Francisco, California.
Dr. Harvey W. Sigmond, Indianapolis, Indiana.
Dr. Homer H. Stryker, Kalamazoo, Michigan.
Dr. F. Eberle Thornton, Iowa City, Iowa.
*Dr. W. P. Warner, Atlanta, Georgia.
Dr. George Whiston, Casper, Wyoming.
*Dr. Irving Wolin, Chicago, Illinois.
Dr. Charles Francis Wood, Louisville, Kentucky.
Dr. H. Herman Young, Rochester, Minnesota.

* Now in Military Service.

The Executive Board of the **American Public Health Association** announces that the Third Wartime Conference and 74th Annual Meeting, and meetings of related organizations, will be held in Chicago, Illinois, the week of September 17, 1945, with headquarters in the Hotel Stevens.

The American College of Surgeons, in expanding its program of Graduate Training in Surgery to assure adequate opportunities for advanced training in surgery, particularly for recent medical graduates when they return from Service with the Armed Forces, has enlarged its headquarters staff in Chicago and announces the following appointments effective immediately:

Major General Charles R. Reynolds (M.C., retired), former Surgeon General of the United States Army, has been appointed Consultant in Graduate Training in Surgery.

Dr. George H. Miller, formerly Dean of the Faculty of Medicine and Chairman and Professor of the Department, American University of Beirut, Lebanon, Syria, has been appointed Director of Educational Activities.

The Department of Graduate Training in Surgery is under the general direction of Dr. Malcolm T. MacEachern, Chairman of the Administrative Board, working with that Board, and responsible to the Committee on Graduate Training in Surgery, of which Dr. Dallas B. Phemister of Chicago is Chairman, and to the Board of Regents.

Surveys of hospitals for Graduate Training in Surgery have been conducted since 1937 by the College. When the war ends in Europe, in order to satisfy the demands of men whose training in surgery was interrupted by war service, together with those of current medical graduates, sufficient opportunities should be ready to offer approved training to men who wish to become surgeons, Dr. MacEachern declares, adding that a competent surgeon according to present-day ideas requires a preparation of three or more years of systematic, supervised graduate training in general surgery or a surgical specialty, following a general internship and graduation from an acceptable medical school.

The biographical data of the first two editions of the **Directory of Medical Specialists** included only positions (internships, residencies, or assistantships) held during the course of training of men up to the time of their certification by the American Boards, and hospital and medical school staff positions then currently held.

In the Third Edition, it is desired to extend this data to include all formal hospital and medical school appointments, with dates held, even though now resigned, as well as records of all military service, including commissions and dates, either in World War I, in the Reserve forces in peace time or in the present War.

Thus, a chronologically complete sketch of a Diplomate's entire career is to be included in this Third Edition of the Directory.

Membership or fellowship in national or sectional (not local) special societies, and national general societies, with offices held, and dates, in any of these, should be reported.

Membership in recognized international medical societies may be included, but honorary or other membership in foreign medical societies should not be reported.

Reference to the Second Edition (1942) of the Directory may be made for lists of medical societies to be included in one's biographical sketch.

Families or secretaries of men absent in military service are asked to complete or correct previous listings on new forms now being mailed to those eligible for inclusion in the Directory. Only those certified by an official American Board can be included.

The foregoing notice is published in response to many inquiries, to assist those certified by the American Board who are now engaged in correcting their previous listings, or preparing new sketches for the Third Edition of the Directory to be published early in 1945.

Communications should be addressed to the Directory of Medical Specialists, 919 North Michigan Avenue, Chicago 11, Illinois.

BARUCH COMMITTEE ON PHYSICAL MEDICINE

The Administrative Board of the Baruch Committee on Physical Medicine has announced the granting of an additional total sum of $185,000.00, which is being given by Mr. Bernard M. Baruch for the further advancement of the program in physical medicine and the physical rehabilitation of those disabled in the War. This sum has been divided into seven grants as follows: $50,000.00 to the Massachusetts Institute of Technology, Cambridge, Massachusetts; $40,000.00 to the Medical School of the University of Minnesota, Minneapolis, Minnesota; $30,000.00 to the Medical School of Harvard University, Boston, Massachusetts; $30,000.00 to the Medical School of the University of Southern California, Los Angeles; $15,000.00 to the Medical School of the University of Iowa, Iowa City; $15,000.00 to the Medical School of the University of Illinois, Chicago; and $5,000.00 to Marquette University Medical School, Milwaukee, Wisconsin.

The grants to the Massachusetts Institute of Technology and to the University of Minnesota are in addition to the gift of $1,100,000.00 made by Mr. Baruch in April of 1944, at which time grants were made to

Columbia University College of Physicians and Surgeons, New York University College of Medicine, the Medical College of Virginia, and for minor research and fellowship programs for the advancement of physical medicine.

The present gift to the Massachusetts Institute of Technology is in support of a five-year program of training and research in electronics, instrumentation, and physics in relation to medicine, to be carried on under the auspices of the Department of Biology and Biological Engineering. It was the conviction of the Scientific Advisory Committee of the Baruch Committee on Physical Medicine that Baruch Fellows and other physicians should have more than a superficial knowledge of the physics and technology underlying the physical methods and instrumentation used in this field, and it was suggested that training in this aspect might effectively be centered at the Massachusetts Institute of Technology. The program will be under the general supervision of Dr. Francis O. Schmitt, Head of the Department of Biology and Biological Engineering, and under the immediate supervision of Dr. K. S. Lion, Assistant Professor of Applied Biophysics, who is an expert in physical instrumentation. Mr. Baruch has been particularly interested in the important field of electronics as applied to medicine.

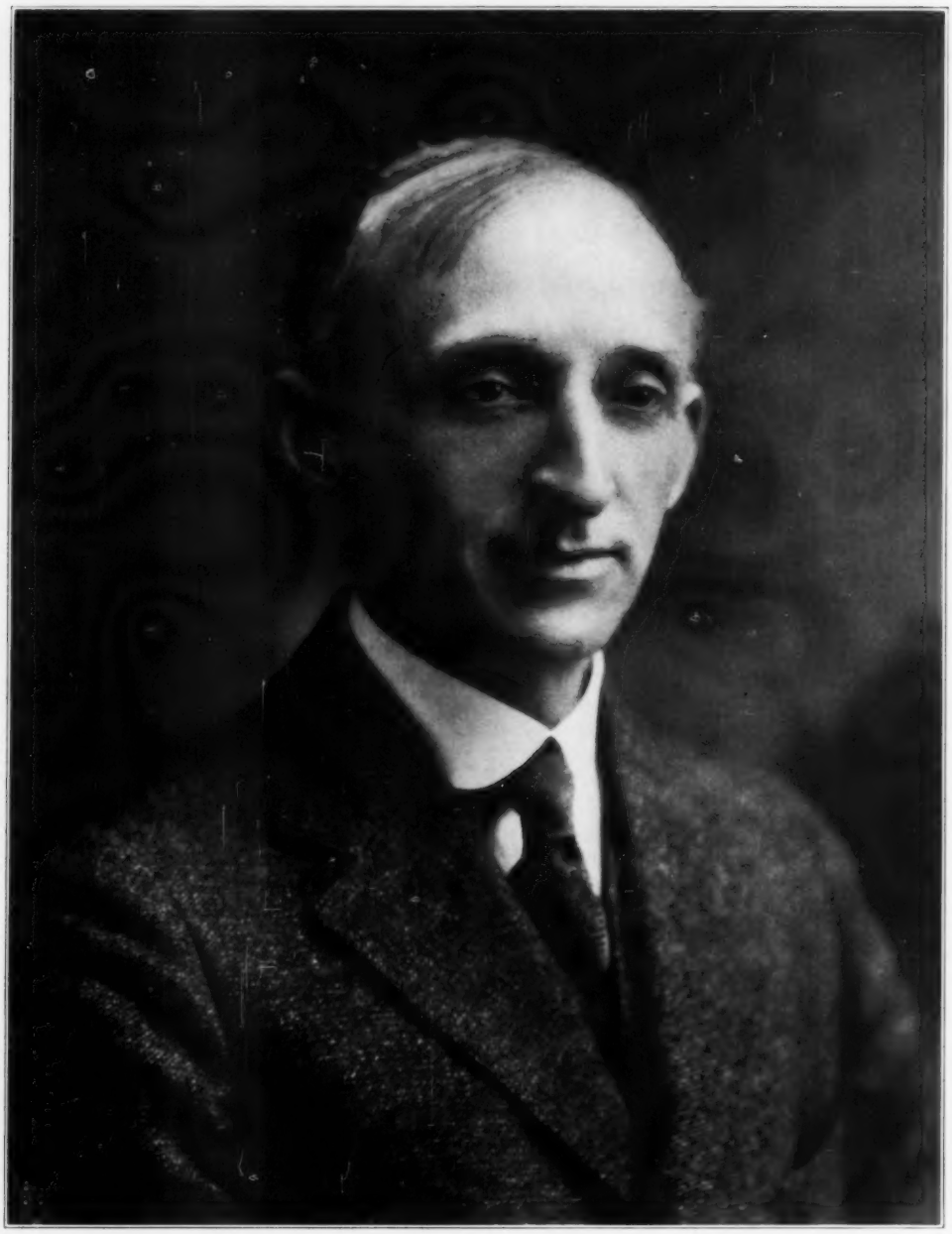
The grant of $40,000.00 to the University of Minnesota is to support the development of a three-year teaching and fellowship program in physical medicine. The primary objective of the program is the furtherance of fundamental training of research workers and teachers in the field of physical medicine.

The other grants have been allocated from the fund of $200,000.00 given by Mr. Baruch in April. The sum of $30,000.00 was granted to Harvard University Medical School for the establishment of a three-year program to provide fellowships or residencies to be used for the benefit of qualified physicians who are selected to be trained in this field. This sum will be administered by a standing Committee on Physical Medicine recently appointed by Dean C. Sidney Burwell of the Harvard Medical School, composed of Dr. J. B. Ayer, Dr. D. Denny-Brown, Dr. W. T. Green, Dr. J. H. Means, Dr. A. L. Watkins, and Dr. E. M. Landis (Chairman). Appointments to the fellowships, which generally carry stipends of $2,500.00, will be made annually, but may be renewed to provide up to three years of specialized study and research. Emphasis will be placed upon training a few men in basic research and clinical investigation.

Unusual opportunities for clinical experience and research in the psychological and psychiatric aspects of physical medicine will be available at Harvard. The first year will be wholly or in part devoted to basic research, related to physical medicine in one of the preclinical sciences, such as physiology, anatomy, or biophysics. The second year will be spent in clinical training in physical medicine at the Massachusetts General Hospital and other hospitals affiliated with the Harvard Medical School. In the third year, fellows will be assistants in physical medicine with clinical responsibilities. For candidates with extensive previous training, one-year clinical fellowships will also be granted. Applicants must have an M.D. degree from an approved medical school, and a minimum of one year of internship in an approved hospital. Applications may be obtained from the Dean, Harvard Medical School, 25 Shattuck Street, Boston 15, Massachusetts.

The sum of $30,000.00 is granted to the University of Southern California to inaugurate a program of teaching and research in physical medicine in its Medical School. The sum of $15,000.00 is granted to the University of Illinois to inaugurate a teaching program in physical medicine at its Medical School. The sum of $15,000.00 is granted to the Medical School of the University of Iowa to assist in a joint research and teaching program concerning the effectiveness of different methods of applying heat to the deep tissues of the human body. Finally, the sum of $5,000.00 is granted to the Medical School of Marquette University, Milwaukee, Wisconsin, for continuance of research in the physiology and pathology of nerves and muscles, as related to physical medicine.

The Baruch Committee will now turn its main attention toward the adequate development of the centers already established, toward providing advice in the organization of proper teaching of physical medicine in medical schools and, through its Committee on War and Postwar Physical Rehabilitation and Reconditioning, will attempt to promote proper development of physical medicine in the rehabilitation and reconditioning of both military and civilian casualties of war. The Board feels that Mr. Baruch's gifts have served as a means of providing prompt coordination of the entire program for rehabilitation of our wounded and for the provision of the trained personnel so greatly needed in activating this program.



MICHAEL HOKE

1874–1944

"The field of action is not the field of intellect: it is the field of character. It is not the intensity but the duration of ideals that makes a great man."

This wise observation of Elihu Root is peculiarly applicable to the life of Dr. Michael Hoke, internationally known orthopaedic surgeon, great teacher, kindly counsellor, and friend.

Dr. Hoke was born in Lincolnton, North Carolina, on June 28, 1874. He was the son of the well-known General Robert F. Hoke and Lydia Van Wyck. General Hoke was, we believe, the youngest Major General in the Confederate Army.

Dr. Hoke's early years were spent in Raleigh, North Carolina. Entering the University of North Carolina, he received the degree of Bachelor of Science in Electrical Engineering in 1893 and was captain of the famous football team of that year. In 1895 he received the degree of Doctor of Medicine from the University of Virginia. Postgraduate study and research then followed at the Medical Schools of Johns Hop-

kins and Harvard. In 1897, he began private practice in Atlanta, Georgia, specializing later in orthopaedic surgery.

On April 20, 1904, he was married to Miss Laurie H. Harrison of Atlanta. The union was a completely happy one, Mrs. Hoke entering fully into both his professional life and his many outside interests. Mrs. Hoke and their two children, Mrs. Charles McGhee of Beaufort, South Carolina, and Mrs. Edward Jastrum of St. Louis, Missouri, and two grandchildren survive him, as does his brother, Mr. Van Wyck Hoke of Yanceville, North Carolina.

Dr. Hoke was a member of The American Orthopaedic Association and its President from 1925 to 1926, presiding at the Annual Meeting of the Association held in Atlanta in 1926. He was a Fellow of The American Academy of Orthopaedic Surgeons. He was one of the five Orthopaedic Consultants for the Shriners' nation-wide chain of Hospitals for Crippled Children, which movement he had sponsored; he was also an important member of the Advisory Board of the Alfred I. Du Pont Institute for Crippled Children at Wilmington, Delaware.

The University of North Carolina conferred on him the honorary degree of Doctor of Laws in 1931. In this same year, at the insistence of President Roosevelt, he accepted the appointment of Medical Director of the Institution for the Treatment of Infantile Paralysis at Warm Springs, Georgia, resigning this position in 1935 to resume his private practice in Atlanta.

Dr. Hoke's contributions to orthopaedic surgery have been many and have been internationally recognized. The original and valuable operative methods he devised for the treatment of certain disabilities of the feet are still known as "Hoke's operation for claw foot" and "Hoke's arthrodesis".

Hoke was a great teacher as well as a great surgeon. He inspired countless young men to acquire surgical skill and to emulate the highest standards of professional conduct which he exemplified. He ploughed the field of medicine deeply, leaving the soil more productive for the labor of those younger physicians who had received their inspiration from him. "History shows you men whose master touch not so much modifies as makes anew"—Browning, had he known him, might well have placed Hoke in this category.

Dr. Hoke's chief relaxations were golf and hunting with the dogs, and he held membership in the Piedmont Driving Club and in the Druid Hills Golf Club. He was a thorough sportsman in the best sense of the word, loving "the wide-open spaces" and "the great out-of-doors".

Although Michael Hoke always felt intensely, and was unswerving in his loyalty to the South, he maintained an unusual breadth of view and was remarkably free from prejudice. On one occasion, he took a northern friend to see the great southern War Memorial on Stone Mountain which was then only partly finished, but the architect's drawings of the completed project were on view and were very impressive. Behind the key figure of General Robert E. Lee, the sculptor had planned to carve a group of other Confederate generals, one of whom would undoubtedly have been Doctor Hoke's famous father, Major General Robert F. Hoke. Dr. Hoke greatly admired the conception and was deeply moved at the thought of what the superb memorial would mean to the South.

As he and his northern friend were moving away, Hoke said to him, "I wish Borglum (the sculptor) would do one more thing. I wish he would place the figure of Abraham Lincoln on the summit of the mountain looking down on the whole group." To Hoke "the war was over", and he had recognized the spirit of the Great Emancipator and wished the South as well as the North to pay him tribute.

This slender ascetic looking man with dark and piercing eyes, a friendly smile, and a delightfully keen sense of humor must have been a sturdy youth in his student days. In later life, pulmonary disease and his strenuous work slowly sapped his strength but never his *bonhomie* nor his endearing kindness.

In 1937, he retired from private practice and moved with his family to the lovely old town of Beaufort, South Carolina. They called their home "Windy Marsh" and for a while Dr. Hoke's health was better, and his passing has come as a shock to his numberless friends.

American Medicine has lost a great orthopaedic surgeon and a great teacher. His standards of both practice and conduct will always inspire physicians, young and old, who have been fortunate enough to catch his spirit.

Justice Oliver Wendell Holmes has given us his ideal of living. "Life is painting a picture, not doing a sum; to hammer out as compact and solid a piece of work as you can; to try to make it first rate and to leave it unadvertised."

Michael Hoke completely exemplified this ideal.

Current Literature

LECTURES ON RECONSTRUCTION SURGERY. Selected from the Instructional Courses of the Twelfth Annual Assembly of The American Academy of Orthopaedic Surgeons. Edited by James E. M. Thomson, M.D. Ann Arbor, Michigan, Edwards Brothers, Inc., 1944. $8.00.

To present a critical analysis of this admirable compilation of the work of a representative group of specialists in the field of reconstructive surgery cannot be done in the space that may be allotted for a review.

All this reviewer can do is to liken it to a symphony, where each instrument having a part is played by an expert in his line. Some instruments have a more important rôle perhaps than others, but no one is any less well played than another, and the summation of effort is a harmonious rendition.

To select some particular papers for special commendation would be invidious; they are all exceedingly well illustrated, clearly presented and are invaluable at this time for anyone who wishes to have the most recent information on the subjects discussed.

SURGERY OF THE HAND. Sterling Bunnell, M.D. Philadelphia, J. B. Lippincott Company, 1944. $12.00.

It is seldom that a book on surgery deserves to be called great. This adjective, often used so carelessly, can be applied with all its implications to "Surgery of the Hand" by Sterling Bunnell. Peculiarly enough, another great surgical treatise, Kanavel's monograph, also dealt with the hand, but limited itself to infections.

Bunnell's book is all-inclusive; nothing connected with the hand has been omitted. The author, in an age of intense specialization, has risen above the confines of a single surgical specialty, and has combined the art of the plastic, orthopaedic, and neurological surgeons. This had to be, for, as he states in his preface, "Trauma involves all types of tissue, irrespective of the artificial divisions of our specialties. . . . As the problem is composite, the surgeon must also be."

As one reads the succeeding pages, one realizes both from the text and the illustrations that here is a surgeon who has learned to "face the situation and equip himself to handle any and all of the tissues in a limb". More than that, his book illustrates his intense desire to teach, to make his own rich experience available to all who want to learn. He has spared nothing to make himself clear, no detail in technique has been too minute to defy careful description, provided it brought out an important principle. His style is that of precise exposition which at times, by its very simplicity, acquires beauty. Take for instance the opening paragraph of the chapter dealing with "The Normal Hand":

"Next to the brain, the hand is the greatest asset to man, and to it is due the development of man's handiwork. It is also an organ of expression and a special sense organ for stereognosis. Our brains are crowded with memories and conceptions of objects and actions which have been built up and developed by sensation and use of our hands. Through hands we have acquired by feeling much of our knowledge of shapes and textures of the objects of this world. Our very thoughts are linked with the sensations and actions of our hands, not only in our fundamental activities concerning shelter, food, combat, and perpetuation, but in constructing, such as building, drawing, sculpturing, and even thinking."

The book is divided into four parts. The first deals with phylogeny and comparative anatomy, and the description of the normal hand; the second with reconstruction of the hand; the third with injuries and infections; and the fourth with miscellaneous conditions,—such as congenital deformities, vasomotor changes, and tumors. Of these, the most important is the second, "Reconstruction of the Hand". The author deals in succession with skin and flexion contractures, bone deformities, stiff joints, injuries to nerves, tendons, and the intrinsic muscles, and, in a final section, to the arm in its relation to the hand.

Though many of the ideas have already appeared in Bunnell's previous publications, it is only when the subject is presented as a whole that one realizes the originality and the unity of Bunnell's contribution to surgery. As an example, he was the first to suture the digital nerves, but this delicate surgical feat was done not as an end in itself, but to aid in the reconstruction of a finger the tendons of which had also been severed. Surgery of the skin, of the bones, of tendons and nerves are all correlated to yield the maximum restoration of function.

It is hard to speak with restraint about this unique volume. It represents to your reviewer the ideal scientific publication; it is brilliantly original, concise yet thorough, so sincere that the honesty and high intent of the author speak in every line. It marks an important milestone in surgical advance. It will assuredly come to be regarded as a classic for those who, like Bunnell, aim to restore power to the hands of the maimed.

ARTRITIS TUBERCULOSA DE LA CADERA. Dr. V. Sanchís Olmos. Madrid, Edicones *Cirugía del Aparato Locomotor*, 1944.

In this monograph on tuberculosis of the hip joint, the best to appear to date in any language, the author has blended skillfully our knowledge of tuberculous infection in general and his wide experience in the treat-

ment of this special type of infection at the *Hospital Central de la Cruz Roja*. The book is well illustrated, and there is a large bibliography. Much of the recent European thought, which has been excluded from American readers, is critically summarized. The author is writing for a Spanish audience, for the purpose of disseminating knowledge of the treatment of tuberculosis of the bones and joints. There has been a great increase in morbidity from tuberculosis in Spain following the recent War.

The symptoms observed in tuberculosis of the hip are dependent upon the oscillations of allergy, and, in this respect, are similar to those seen in pulmonary infection. Osseous or articular involvement occurs during the secondary period of allergy, by the hematogenous route from some primary visceral implantation, and results either in medullitis or synovitis. He feels that the doctrines of Ranke and Redeker, while helpful, do not explain fully the pathological phenomena. He agrees with Auer that infection is enhanced in tissues whose reactivity has been altered, for example, by trauma. Repeated microtrauma may favor the localization. There may be primary involvement of the synovial membrane, infection of the synovial membrane secondary to an abscess, or primary involvement of bone. Usually the disease is so far advanced when seen that the primary focus cannot be determined. The pathological reaction in the bone or joint may be caseous, exudative, or granulomatous during the secondary stage of the tuberculosis. Urbach attempts to explain the vigorousness of the reaction and the necrosis of tissue which occurs upon the basis of the relative proportion of antigen and antibody present in the tissues. Caseation is rare in synovitis, but is common in osseous lesions. Vascularization of the tissues about the hip joint explains the predilection for certain areas. Infection is rarest in the ischium and pubis. Primary synovitis is rare indeed. Osteo-arthritis originating in an osseous focus often leads to extensive necrosis and abscess. Osteo-arthritis originating in a synovial focus is often limited to cartilaginous destruction and early fusion of the joint.

There is a wide immunobiological lability with great variation in symptoms and reparative response. If the state of hypersensitivity is much prolonged, abscess, fistula, and death may occur. The tertiary phase of tuberculous infection often leads to unsound healing. The only type which leads to sound, anatomical cure is the rapidly exudative type which produces conditions favorable for osseous fusion. The appearance of abscess is in direct proportion to the violence of the exudative phenomena.

Deformities are divided into two types which may appear in both the secondary and tertiary phases of the infection: (1) contractures or ankylosis in a bad position and (2) loss of all normal anatomical relationships with pathological dislocation. Trophic disturbances and interference with growth are not uncommon. Perifocal hyperaemia provokes local acidosis, which frees calcium salts. This is a constant phenomenon in tuberculous infection, and is most marked in the exudative type. The osteoporosis which results lessens the mechanical resistance of the bone. Bone atrophy is also partly the result of immobilization. Decalcification diminishes with regression of exudative phenomena. Epiphysiolysis is rare. Ossification may be increased under the periosteum. Variations in growth may be seen in different parts of the epiphysis.

Early diagnosis by roentgenographic examination is difficult. The first sign is focal osteoporosis. Serial roentgenograms will show the progression of the lesion. (Lesions in the cartilage appear late.) The common physical signs of tuberculous infection are usually found. A negative reaction to tuberculin almost completely eliminates the diagnosis of tuberculous infection. The sedimentation rate of the erythrocytes is moderately elevated. Biopsy is occasionally necessary. The differential diagnosis is outlined. The prognosis is always serious.

Treatment should be both general and local. Under the general treatment, the author mentions sunlight, adequate nutrition and calcium, and sulphonamides for sinuses. Locally, osseous ankylosis with the hip in a good position is sought. Fibrous ankylosis can be regarded as an inactive tuberculous focus cured clinically, but not anatomically. Local extirpation removes only one latent focus and can only be resorted to in areas easily accessible anatomically. The position of ankylosis will be dependent upon the socio-economic status of the patient. The joint is rarely preserved in the healing of tuberculosis. Even Rollier and Kisch now speak of arthrodesis as the treatment of choice. During the secondary phase of infection, general treatment is fundamental, and orthopaedic treatment which facilitates this should be given.

Surgical intervention should be undertaken during the tertiary period. Age is no contra-indication to surgery. The author does not hold to the teaching of Sorrell and the Congress of 1927, which advocated conservatism in childhood, arthrodesis in maturity, and amputation in the aged. The author gives the following as his formula of therapy: in the tertiary phase, surgical treatment directed to ankylosis; in the hyperergic phase, conservative treatment; in the phase of local hyperergia, extra-articular intervention when the general state of the patient indicates.

In minor tuberculous affections and where there is a para-articular focus, simple prolonged rest in bed may be all that is required. Synovitis, osteo-arthritis, and juxta-articular foci require absolute immobilization. If there is a fistula, a bilateral spica with a window is needed. The hip is maintained in 10 degrees of flexion, 15 degrees of abduction, and no rotation. The author prefers continuous traction to a plaster cast, because in traction the skin is exposed more fully to the sun and air.

Fusion is carried out by a procedure similar to the Hibbs-Chandler technique. Contractures are corrected by traction,—skeletal traction if necessary. Vicious ankylosis is corrected by subtrochanteric osteotomy. Flexion depends upon the vocation of the individual. Abduction should be 5 degrees in men and 15 degrees

in women. Recent dislocation is reduced by traction. After reduction of a dislocation, an athrodesis is performed. Shortness of the extremity can be improved up to six centimeters by leg lengthening. If the difference is greater than this, the sound leg can be shortened. In involvement of both hips, an arthroplasty can be attempted on one side, after the arthrodesis has healed. Motion should be preserved in one hip if possible, during the healing of the tuberculosis.

The author feels that patients with such infection should not be treated on the general service of hospitals, but should be segregated in special hospitals or sanitoria where specialized care can be given.

TREATMENT BY MANIPULATION IN GENERAL AND CONSULTING PRACTICE. A. G. Timbrell Fisher, M.C., M.B., Ch.B., F.R.C.S. (Eng.). Ed. 4. New York, Harper & Brothers, 1944. $4.75.

The new edition of this work on manipulative surgery is written because of the author's belief in the importance of manipulative treatment of orthopaedic conditions resulting from war injuries. After a short historical introduction, the lesions benefited by this type of therapy are discussed according to the pathological findings.

There are four main classifications used: (1) articular or periarticular adhesions, (2) functional or hysterical conditions of joints, (3) subluxations and dislocations of joints, tendons, or intra-articular discs, (4) adhesions in connection with muscles, tendons, or fascia. In the prevention of adhesions, early motion is stressed and the dangers of prolonged rest and splintage are emphasized. Instruction in the degree and type of motion permitted in a variety of pathological conditions is carefully presented. As the primary indication for manipulation is the presence of adhesions, a chapter is devoted to their diagnosis.

The actual procedure of manipulation, preferably under an anaesthetic such as pentothal, is described for all the major joints, with suitable illustrations and brief case histories of the clinical findings. Contra-indications to manipulation, such as tuberculosis and neoplastic disease, are pointed out. Although one feels that the author expects almost universally good results, the use of other measures—such as splintage, traction, and surgery—are recommended in some instances. The importance of adequate physical therapy in the after-care of manipulative cases is repeatedly stressed. A chapter is devoted to description of the technique in use of heat, massage, and exercises. The author further states that no medical man should perform a manipulation unless he has made a study of massage, muscle re-education, and the methods of physical treatment that are of use in after-care.

Although among American physicians "manipulation" frequently has had bad connotations, the subject is presented in this book in a fairly cautious and studied manner. One might wish to have more precise information on the problem of choice of case to manipulate rather than broad statements, such as "The most frequent indications for (spinal) manipulations are those cases in which adhesions or scar tissue in muscles, ligaments, or fasciae have followed either toxic or infectious conditions, or ligamentous or muscular injuries". There is, however, much valuable information worthy of study by orthopaedic surgeons and those specializing in physical medicine.

STRUCTURE AND FUNCTION AS SEEN IN THE FOOT. Frederic Wood Jones, D. Sc., F.R.S., F.R.C.S. Baltimore, The Williams & Wilkins Company, 1944. $7.50.

Professor Wood Jones's eminent position as an anatomist and physical anthropologist and the importance of the foot to man's locomotor mechanism should amply recommend this book to all orthopaedic surgeons. The text is interestingly written and thought-provoking. Even though the author may not win ready acceptance of all his statements, he will not fail to stimulate a healthy, thoughtful reaction among his readers.

The opening chapter affirms the unique and highly specialized character of the human foot. The distinctive design of the foot separates mankind from all other forms of vertebrate life, and as an organ, its structures have been molded specifically for one purpose,—"support and propulsion of the body in bipedal orthograde progression". He emphasizes, also, the basic difference between hand function and foot function, and warns that the structural homologies in these two organs should not be allowed to obscure a clear recognition of the difference in our approach to the clinical considerations of foot disabilities. The human hand is primitive in its design, and is little changed from the hands of all lower primates; its superior qualities are represented only in a higher degree and range of skilled actions. In contrast, the human foot has been so extensively remodeled for direct interaction with the force of gravity (beneath the weight of our bodies), that its former handlike, grasping characteristics have become almost completely replaced by the specialized structural changes required for stable support and propulsive leverage.

The author's discussion of muscle action should also be of more than ordinary interest to orthopaedic readers. Not only does the author recognize the "controlling" action of the extrinsic muscles of the foot, in contrast to the "supporting" action usually ascribed to them, but he also explains the *reversed* direction of their action, as compared with the muscles of the hand. In the forearm, the muscle *origins*, located proximally, serve as the fixed point from which movements of the digits and hand are effected; in the lower extremity, the tendinous *insertions* upon the distal bony segments serve as the fixed points from which muscle

action is enabled to control posture and the movements of body weight. Both of these observations have practical therapeutic bearing on corrective and surgical work on the foot.

The book is a comprehensive treatise of all the tissues entering into the make-up of the foot,—skin, fascia, muscles, ligaments, bones, joints, and vascular and nerve structures. As might be expected, the discussion of these tissues is accompanied by interesting comments relating to their development, both phylogenetic and ontogenetic. The author has avoided any attempt to supply a definite evolutionary background. His chapter on phylogeny consists chiefly of a critical statement on the views held by different writers regarding the point of human origin. The concept usually associated with his name places that point far back in a "tarsioid" branch of early primate life. His claims to the general acceptance of that belief are somewhat surprising, and seem as controversial as the "tarsioid" theory, itself, which he so strongly advocates. Naturally, his interpretations of development are influenced by that concept.

The text reflects Professor Wood Jones's wide familiarity with the literature contributed by older and more recent writers on the various phases of the subject. He brings in references that enhance interest and will inevitably broaden the reader's viewpoint. However, the book is distinctly the product of a *morphologist*. This is strikingly indicated by the author's discussion of the "metatarsal formula". Here he discounts, almost derides, the possibility of there being any functional or clinical significance in a short first metatarsal bone; he prefers to regard that condition as "the accepted normal of all anatomists". Such apparent unwillingness to permit a morphological conclusion to be disturbed by the physiological studies and clinical observations of other writers hardly contributes to the strength of Professor Wood Jones's arguments, but does not detract from the colorfulness of the presentation. In fact, it is in the physiological phase that the book invites a feeling of disappointment, because, after having identified the foot as an organ designed specifically for its interaction with the force of gravity (as imposed by body weight), the author fails to follow up his statement with further consideration of that essential aspect of foot function. It is like reading a treatise on the eye in which every structure related to the eyeball is fully discussed, but no mention is made of refraction, the phenomenon whereby the vital purpose of the eye as the organ of vision becomes fulfilled. In the same way that an orderly transmission of light rays through the eyeball is a basic factor in eye function, the behavior of weight stresses (gravity) within the foot structure comprises the fundamental phase of foot function. However, the intimate morphology of the eye was a prerequisite to the understanding of the refractive elements of sight. The work of Professor Wood Jones is to be regarded as an important contribution to our morphological knowledge, which will prepare the way toward clearer understanding of the less obvious, but more basic phase of the foot's function.

ORTHOPAEDIC SURGERY. By Walter Mercer, M.B., Ch.B., F.R.C.S. (Edin.), F.R.S. (Edin.). With a Foreword by Sir John Fraser, Bart., K.C.V.O. Ed. 3. London, Edward Arnold & Co., 1943. 45 shillings. Baltimore, The Williams & Wilkins Co., 1943. $12.00.

The third edition of Mercer's textbook on orthopaedic surgery has been revised chapter by chapter to include new material on each subject. The sections on Circulatory Disturbances, Affections of the Back, Knee, Shoulder, and Foot, and Infections of the Hand, have been largely rewritten.

The text is well illustrated with photographs, line drawings, and roentgenograms which add much to the clear presentation of the anomalies and the diseases of bones and joints.

The author has indicated his choice of treatment and operative procedure in some conditions.

The text is thoroughly indexed, and the complete bibliography, including many American and British authors, should prove an invaluable reference to the student or doctor.

REHABILITATION, RE-EDUCATION AND REMEDIAL EXERCISES. Olive F. Guthrie Smith, M.B.E., C.S.M.M.G., T.M.G. With a Foreword by Lord Horder, G.C.V.O., M.D., F.R.C.P. Baltimore, The Williams & Wilkins Company, 1943. $6.00.

The physical treatment, described in this book by contributors distinguished in various fields of therapy, is confined largely to suspension exercises and pulley therapy. A revision of theoretical joint axes from an anatomical and physiological viewpoint, including plates which demonstrate planes and axes, precedes the classification of the various joints of the body.

The principles of re-education in flaccid and spastic paralyses are explained by means of a pendulum-suspension rhythm and muscle-timing apparatus.

Voluntary exercises are stressed, as are self-activated exercises, which employ simple appliances in the hands of a skilled therapist. Long helical or spirally curved springs are recommended for the treatment of enfeebled or injured muscles. They may be adjusted to the needs of the patient, so as to apply either assistance or resistance to the exercises.

Descriptions of the use of graduated faradic contractions for the stimulation of one group of motor nerves are included; group exercises, as used at the Berry Hill Hall Rehabilitation Center, are recorded; and different methods of muscle-testing are suggested.

Various pathological conditions and their treatment by relaxation and corrective exercises are considered, and illustrations show pulley and rope exercises for the lower and upper extremities.

As the title infers, the work is concerned chiefly with remedial and re-educational exercises. Apparatus and appliances play an important rôle in the book.

Other branches of physiotherapy are mentioned,—such as, heat, short wave and ultra-short wave, galvanic and sinusoidal currents, histamine ionization, and massage; however, these are considered as side issues rather than as part of a well-defined text.

The book is well and fully illustrated.

OPERATIONS OF GENERAL SURGERY. Thomas G. Orr, M.D. Philadelphia, W. B. Saunders Company, 1944. $10.00.

The expressed purpose of this excellent volume is the familiarizing of students with standard operations in all fields of surgery. Of special interest to the orthopaedic surgeon are: Chapter 4, "Amputations", Chapter 6, "Muscle, Fascia, and Bursa", and Chapter 7, "Tendons and Tendon Sheaths". Chapter 14, "Bones and Joints", has forty-six pages of concentrated orthopaedics, starting with the treatment of acute and chronic osteomyelitis, strongly advocating the method of Winnett Orr. In the treatment of fractures, standard operative procedures are described in regard to certain specific conditions, including fractures of the olecranon, head of the radius, condylar and supracondylar fractures of the humerus, patella, femoral condyles, and so on. The chapter concludes with descriptions of special operations,—such as those for the dislocation of the patella, dislocation of the shoulder, dislocation of the hip, acromioclavicular separation, injury to the semilunar cartilage of the knee, and hallux valgus. For each of these conditions, one or two standard procedures are described.

The chapters reviewed comprise only a small portion of the book, the rest of which includes descriptions of operations on the breast, thorax, circulatory system, digestive system, and many others. It is freely illustrated with distinctive drawings and diagrams showing step-by-step procedures in each of the standard operations. The book serves its purpose well in indicating to the student of general surgery not only the standard procedures in general surgery, but also in surgical specialties with which he should be familiar.

FRACTURES AND FRACTURE TREATMENT IN PRACTICE. Kurt Colsen, M.D. Ed. 2. Johannesburg, Witwatersrand University Press, 1944. 12 shillings, 6 pence.

This book of 150 pages is introduced to the students of the University of the Witwatersrand at Johannesburg by the Professor of Surgery, I. W. Brebner. It presents in Part I certain general considerations, intended to orient the student, who will find in Part II special fractures described and some form of treatment advised and pictured by line drawings. The author has made a brief review of the various fractures, depending very evidently upon the writings of Böhler and Watson-Jones.

The subject presented is one of the most important in surgery. Undoubtedly under the skilled presentation and instruction of the author, his students will receive adequate impressions of the close relationship between the problems attending fractures and those of many other specialties in surgery.

MICROBES THAT CRIPPLE. T. Arthur Turner. (Written and Illustrated under the Direction of Edward L. Compere, M.D.) Elyria, Ohio, The National Society for Crippled Children, Inc., 1944. $2.50.

This book is written for the layman. It presupposes no knowledge of science. From the construction of the microscope by Jansen in 1590 to the electron microscope of the present, with the field it opens, the story of the lens is traced. So too are the organisms revealed by the microscope. A little of the history of the recognition of their existence and of the men who first isolated and named them is given.

The classification of bacteria and other infectious agents is presented in an interesting, simple style. The principles of immunization are discussed, and the laboratory methods used are explained. The diseases produced by "crippling micro-organisms" are then described,—pyogenic osteomyelitis, tuberculosis, syphilis, and poliomyelitis. Rheumatic fever, arthritis, and gonorrhoea are recognized as "cripplers"; and the complications of various diseases of childhood are explained.

The last portion of the book is devoted to an exposition of the progress made in combatting these diseases,—the public health program with its educational aspect for the prevention of crippling, the history of chemotherapy, and the fight against poliomyelitis.

Such a book, written in cooperation with men whose lives are devoted to the correction and prevention of congenital and acquired deformities, has its place in medical literature. Written in language which the layman can understand, and presented in popular format with clever illustrations, it should have a wide reading. For the mother who has read this book, "microbes that cripple" will have fewer terrors.